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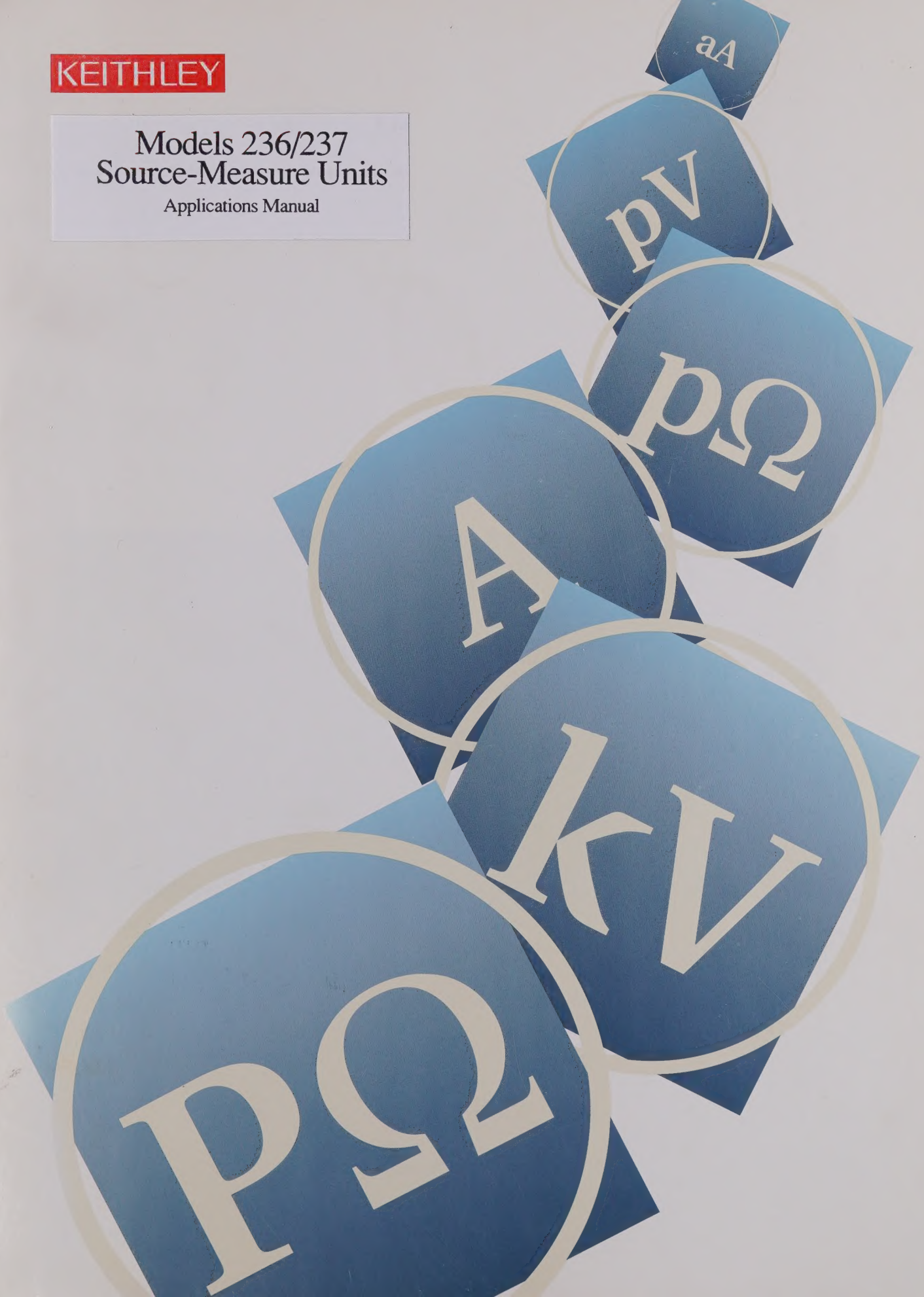
Models 236/237 Source-Measure Units

Applications Manual



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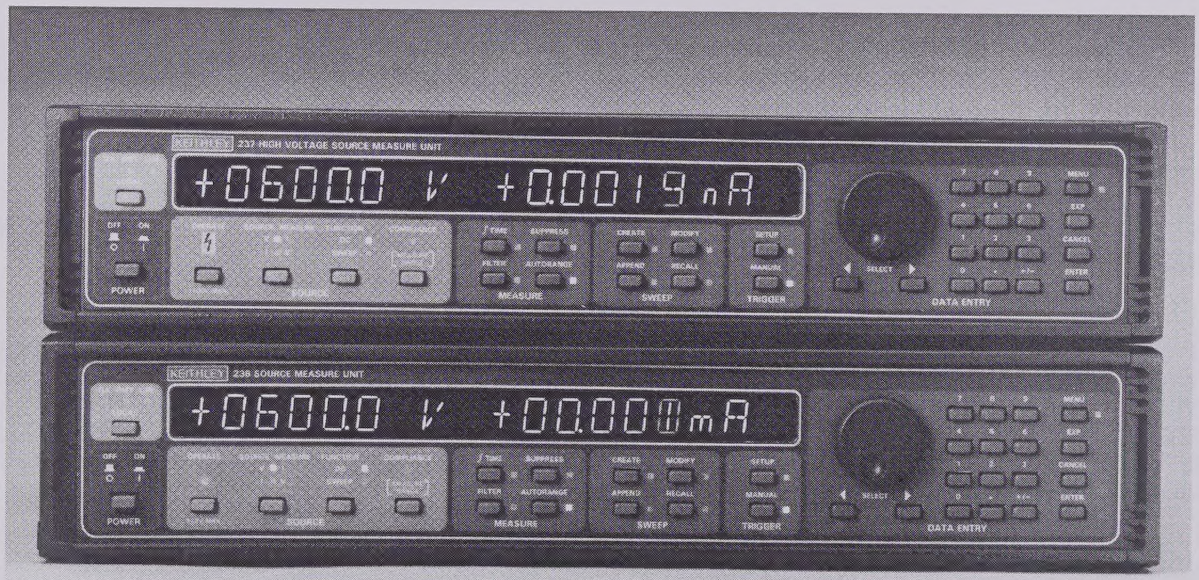

Contains Programming Examples

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Model 236 Source-Measure Unit
Model 237 High Voltage Source-Measure Unit
Applications Manual

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SAFETY PRECAUTIONS

The following safety precautions should be observed before using Model 236/237 Source Measure Units.

The Model 236/237 Source Measure Unit is intended for use by qualified personnel who recognize shock hazards and are familiar with the safety precautions required to avoid possible injury. Read over the operator's manual carefully before using the instrument.

Exercise extreme caution when a shock hazard is present. Lethal voltages may be present on the test fixture or the Source Measure Unit connector jacks. The American National Standards Institute (ANSI) states that a shock hazard exists when voltage levels greater than 30V RMS or 42.4V peak are present. A good safety practice is to expect that hazardous voltage is present in any unknown circuit before measuring.

Inspect the connecting cables, test leads, and jumpers for possible wear, cracks, or breaks before each use.

For maximum safety, do not touch the Source Measure Unit, test fixture, test cables or any other instruments while power is applied to the circuit under test. Turn off all power and discharge any capacitors before connecting or disconnecting cables or jumpers. Also, keep the test fixture lid closed while power is applied to the device under test. Safe operation requires the use of the lid interlock.

Do not touch any object which could provide a current path to the common side of the circuit under test or power line (earth) ground. Always make measurements with dry hands while standing on a dry, insulated surface capable of withstanding the voltage being measured.

Do not exceed the maximum signal levels of the test fixture, as shown on the rear panel and as defined in the specifications and operation section of the instruction manual.

Connect the ⏚ screw of the test fixture to safety earth ground using #18 AWG or larger wire (supplied accessory).

Instrumentation and accessories should not be connected to humans.

The ⚡ symbol on a Model 237 indicates that 1000V or more may be present on the terminals. Refer to the Model 236/237 Operator's Manuals for detailed operation information.

When a Model 236/237 is programmed for remote sensing, hazardous voltage may be present on the SENSE and OUTPUT terminals when the unit is in operate regardless of the programmed voltage or current. To avoid a possible shock hazard, always turn off all power before connecting or disconnecting cables to the Source Measure Unit or the associated test fixture.

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PREFACE

This Applications Manual is intended to demonstrate a number of key applications for the Models 236 and 237 Source Measure Units. Typical applications covered in this manual include: diode forward characteristics, common-emitter and common-source characteristics, current gain, threshold tests, and Gummel plots. Additional applications include using Source Measure Units with other instruments such as voltage sources, current source, and electrometers. Finally, several switching system examples are included to demonstrate how to increase the versatility of a Source Measure Unit test system.

Each application includes an example program written in Hewlett-Packard BASIC 4.0 to demonstrate programming principles, and all applications are intended to run on Hewlett-Packard Series 200 and 300 computers. The programs can be converted to run on IBM PC and compatible computers using Microsoft QuickBASIC, as outlined in Appendix A.

Before using these applications, you should become thoroughly familiar with the operation of your Model 236 or 237 Source Measure Unit. Refer to the Model 236/237 Operator's Manual, supplied with the instrument, for detailed information on operation.

PROGRAM SYNOPSIS

A brief description of each example program in this manual is given below. Programs 1, 2, 3, 8, and 23 require only one Model 236 or 237 to operate. The remainder of the programs require two or more Source Measure Units, or one Source Measure Unit and at least one additional instrument such as a voltage source, current source, scanner, or switching matrix.

Program 1: Resistor Voltage Coefficient Test Program. This program requires only one Source Measure Unit, and it is intended to test the voltage coefficient of resistors. User-programmed voltage test values are used, and the current through the resistor under test is measured by the Source Measure Unit. The resistance and values and voltage coefficient are computed by the program. (pp. 2-2 to 2-7)

Program 2: Capacitor Leakage Test Program. Program 2 allows you to test leakage current values of capacitors using a single Source Measure Unit. User-input test voltage and delay values are used, and the program displays both leakage current and leakage resistance. (pp. 2-8 to 2-11)

Program 3: Diode Characterization. Program 3 determines the variability of forward voltage, V_F, as the forward current, I_F, is varied across a certain range. Once test data are compiled, a plot of V_F vs. I_F is generated on the computer CRT. (pp. 2-12 to 2-16)

Program 4: Common-emitter Characteristics. This program performs standard common-emitter characteristic tests of a typical small-signal NPN bipolar transistor. Two Model 236 or 237 Source Measure Units are required to run the program, with one unit sweeping I_B, and the second unit sweeping V_{CE} and measuring I_C. A total of five I_B values are used, and, at the conclusion of the test, a plot of all five I_C vs. V_{CE} curves is generated. (pp. 3-3 to 3-7)

Program 5: Gummel Plot. Program 5 provides a Gummel plot of an NPN bipolar transistor with log(I_B, I_C) plotted vs. V_{BE}. Two Model 236 or 237 Source Measure Units are required; the first unit sweeps V_{BE} and measures I_B, and the second unit sources V_{CE} and measures I_C. (pp. 3-8 to 3-12)

Programs 6A and 6B: Dc Current Gain. Programs 6A and 6B allows dc current gain testing of an NPN transistor using two Model 236 or 237 Source Measure Units. One Source Measure Unit provides the base current, I_B, and the second unit sources V_{CE} and measures I_C. Program 6A automatically sets the base current to the correct value based on user-input target I_C. Program 6B demonstrates a high-speed current gain test method using special characteristics of the Models 236 and 237. (pp. 3-13 to 3-20)

Program 7: Differential Current Gain. This program allows you to enter two incremental base current values to determine the differential current gain of NPN bipolar transistors. The result approximates the ac current gain of the devices. One unit supplies the base current, and the second unit sources V_{CE} and measures I_C at each base current value. (pp. 3-21 to 3-23)

Program 8: Transistor Leakage Current. Using one Source Measure Unit, Program 8 measures the leakage current, I_{CEO}, as the reverse bias voltage, V_{CEO} is varied. The program generates an I_{CEO} vs. V_{CEO} plot after data are collected. (pp. 3-24 to 3-28)

Program 9: Common-Source Characteristics. This program uses two Source Measure Units to generate FET common-source characteristics. The first Source Measure Unit is used to sweep V_{GS}, and the second unit is used to sweep V_{DS} and measure I_D. Curves at five different V_{GS} values are generated by the program. (pp. 4-2 to 4-7)

Program 10: Transconductance vs. Gate Voltage. Program 10 generates a plot of g_{fs} vs. V_{GS} for a typical FET. Transconductance is computed from small, incremental changes in V_{GS} and the resulting changes in I_D. Two Model 236 or 237 Source Measure Units are required to use this program. (pp. 4-8 to 4-12)

Program 11: Transconductance vs. Drain Current. This program generates a plot of V_{GS} vs. I_D for an FET. Again, g_{fs} is computed from incremental V_{GS} and I_D values, and two Source Measure Units are required. (pp. 4-13 to 4-16)

Programs 12A and 12B: Threshold Voltage. Program 12A allows you to determine the threshold voltage of a typical FET at a specified drain current value. Two Source Measure Units are required for the program which includes an iterative search for target I_D. Program 12B demonstrates the self-bias threshold test, which is much faster, and showcases some special capabilities of the Models 236 and 237. (pp. 4-17 to 4-24)

Program 13: Substrate Current vs. Gate Voltage. Three Source Measure Units are required for Program 12, which generates a plot of substrate current, I_{SB}, vs. gate voltage, V_{GS}. One unit sweeps V_{GS}, the second unit sources V_{DS}, and the third unit sources V_{SB} and measures I_{SB}. (pp. 5-4 to 5-8)

Program 14: Common-source Characteristics with Source Measure Unit Substrate Bias. Program 14 adds substrate-bias programming for a third Source Measure Unit to a common-source characteristic test program. The program generates a plot of I_D vs. V_{DS} at five V_{GS} values. (pp. 5-9 to 5-14)

Program 15: Common-source Characteristics with Voltage Source Substrate Bias. Program 15 uses a Model 230 Voltage Source to provide substrate bias for the device under test. Two Model 236 or 237 Source Measure Units are also required to run the program, which generates I_D vs. V_{DS} curves at five different V_{GS} values. (pp. 5-15 to 5-19)

Program 16: Common-emitter Characteristics with Voltage Source Substrate Bias. Program 16 uses a Model 230 Voltage Source to provide substrate bias when measuring common-emitter characteristics. Two Source Measure Units are required in addition to the voltage source to run this program, which generates I_C vs. V_{CE} curves at five I_B values. (pp. 5-20 to 5-24)

Program 17: Common-emitter Characteristics using Current Source. Program 17 is one of several programs that demonstrate techniques for using a Source Measure Unit with other instruments. In this instance, a Model 220 Current Source is used to sweep the base current under program control, while a Model 236 or 237 Source Measure Unit is required to sweep V_{CE} and measure I_C. The program generates I_C vs. V_{CE} curves at five different I_B values. (pp. 6-1 to 6-6)

Program 18: Common-source Characteristics using Electrometer. This program utilizes a Model 617 Electrometer to sweep V_{DS} under program control and to measure I_D. A Source Measure Unit is necessary to sweep V_{GS}, and the program generates I_D vs. V_{DS} curves at five V_{GS} values. (pp. 6-7 to 6-12)

Program 19: Power Transistor Testing. Program 19 demonstrates using a Model 228A Voltage/Current Source in conjunction with a Source Measure Unit to test power transistor current gain. The Source Measure Unit is used to provide base current, while the Model 228A Voltage/Current Source is used to source V_{CE} and to measure I_C. (pp. 6-13 to 6-18)

Program 20: Dc Current Gain with Scanning. Program 20 demonstrates using a Model 705 Scanner to test a number of DUTs with one test system. Two Model 7058 Low Current Scanner Cards and two Source Measure Units are also required for the program, which can test the current gain of up to ten transistors. (pp. 7-1 to 7-7)

Program 21: Resistivity Test Program. Program 21 demonstrates techniques for determining the resistivity of devices. In addition to a Model 236 or 237 Source Measure Unit, the program also requires a Model 705 Scanner equipped with a Model 7152 Low Current Matrix Card. Following measurement, the program automatically calculates and displays resistivity values. (pp. 7-7 to 7-14)

Program 22: Using a Switching Matrix to Test Transconductance. This program uses a Model 707 Switching Matrix and a Model 7072 Semiconductor Matrix Card to demonstrate programming principles associated with matrix operation. In addition to the switching matrix, two Model 236 or 237 Source Measure Units are required for the program, which tests for and calculates the transconductance of one of three selected DUTs. (pp. 7-14 to 7-23)

Program 23: Binary Transfer Diode Characterization Program. Program 23 tests the forward characteristics of typical diodes using one Model 236 or 237 Source Measure Unit. The program demonstrates how to optimize measurement speed by using the binary data format to speed up IEEE-488 bus data transmission. Once data are taken, the program generates a V_F vs. I_F plot on the computer CRT. (pp. 8-3 to 8-9)

Program 24: Binary Transfer Common-emitter Program. This program shows binary transfer methods as applied to common-emitter characteristic testing. Two Model 236 or 237 Source Measure Units are required by the program, with one unit sweeping I_B, and the second unit sweeping V_{CE} and measuring I_C. The program generates I_C vs. V_{CE} plots for five I_B values after device testing is complete. (pp. 8-10 to 8-15)

Program 25: Self-bias Threshold Tests with Plotting and Binary Transfer. This program demonstrates techniques for plotting V_T vs. I_D using the self-bias method for threshold measurement. (pp. 8-16 to 8-22)

Program 26: Log Sweep Threshold Test with Plotting: Program 26 performs essentially the same type of test as Program 25 with modifications to generate and plot a log sweep for a wider range of test currents. (pp. 8-16 to 8-23)

IBM-PC/QuickBASIC Programs (Appendix A)

Program A-1: Diode Characterization. Program A-1 determines the variability of forward voltage, V_F, as the forward current, I_F, is varied across a certain range. Once test data are compiled, a plot of V_F vs. I_F is generated on the computer CRT.

Program A-2: Transistor Leakage Current: Using one Source Measure Unit, Program A-2 measures the leakage current, I_{CEO}, as the reverse bias voltage, V_{CEO} is varied. The program generates an I_{CEO} vs. V_{CEO} plot after data are collected.

Program A-3: Common-Emitter Characteristics. This program performs standard common-emitter characteristic tests of a typical small-signal NPN bipolar transistor. Two Model 236 or 237 Source Measure Units are required to run the program, with one unit sweeping I_B, and the second unit sweeping V_{CE} and measuring I_C. A total of five I_B values are used, and, at the conclusion of the test, a plot of all five I_C vs. V_{CE} curves is generated.

Program A-4: Common-Source Characteristics. This program uses two Source Measure Units to generate FET common-source characteristics. The first Source Measure Unit is used to sweep V_{GS}, and the second unit is used to sweep V_{DS} and measure I_D. Curves at five different V_{GS} values are generated by the program.

Program A-5: Log Sweep Threshold Test with Plotting. Program A-5 performs the self-bias threshold test and plots a log sweep of the results.

Program A-6: Gummel Plot. Program A-6 provides a Gummel plot of an NPN bipolar transistor with log (I_B, I_C) plotted vs. V_{BE}. Two Model 236 or 237 Source Measure Units are required; the first unit sweeps V_{BE} and measures I_B, and the second unit sources V_{CE} and measures I_C.

HOW TO USE THIS MANUAL

Outlines the overall system configuration and computer software required to run the example programs in this manual.	**SECTION 1** General Information
Describes typical test procedures for two-terminal devices such as high-megohm resistors, diodes, and capacitors.	**SECTION 2** Two-terminal Device Tests
Details typical bipolar transistor tests such as common-emitter characteristics and Gummel plots.	**SECTION 3** Bipolar Transistor Tests
Covers typical FET tests such as common-source characteristics and transconductance tests.	**SECTION 4** FET Tests
Describes using a Source Measure Unit or separate voltage source to provide substrate bias for semiconductor tests.	**SECTION 5** Using Substrate Bias
Discusses using Source Measure Units with other types of instruments such as current sources and electrometers.	**SECTION 6** Using Source Measure Units with Other Instruments
Outlines methods to add scanner and matrix switching capabilities to a Source Measure Unit test system to increase system versatility.	**SECTION 7** Adding Switching Capabilities to a Source Measure Unit Test System
Describes ways to maximize data throughput in a Source Measure Unit test system by using such features as binary data transfer.	**SECTION 8** Optimizing Measurement Speed

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SECTION 1
General Information

1.1 INTRODUCTION

The following paragraphs discuss the overall hardware and software configuration of the system necessary to run the example applications programs in this manual.

1.2 HARDWARE CONFIGURATION

1.2.1 System Configuration

Figure 1-1 shows the overall hardware configuration of a typical Source Measure Unit test system. The various components in the system perform the following functions:

Model 236/237 Source Measure Units: Each Model 236/237 Source Measure Unit can source voltage and simultaneously measure current, or source current and simultaneously measure voltage. One unit is necessary to run two-terminal device tests, while two units are required to run the bipolar transistor and FET tests. If programmable substrate bias is required, a third Source Measure Unit or a programmable voltage source will be necessary.

Model 8006 Test Fixture: The test fixture is the interface between the DUT (device under test). The Model 8006 includes sockets for axial-component, TO package, and 24-pin DIP package devices.

Computer: A Hewlett-Packard 9000 Series 200 or 300 computer equipped with an HP-IB interface controls the test system. An HP BASIC language processor card, installed in an IBM-PC, AT or compatible computer, can also be used.

Connecting Cables: Model 7078-TRX-3 triax cables are recommended for making connections between the Source Measure Units and the test fixture. In addition, IEEE-488 cables will be necessary to connect the Source Measure Units to the IEEE-488 (HP-IB) bus of the computer. Shielded IEEE-488 cables such as the Model 7007 are recommended for this application.

1.2.2 Remote/Local Sensing Considerations

In order to simplify test connections, most applications in this manual use local sensing for the Source Measure Units. Local sensing requires connecting only two cables between the Source Measure Units and the test fixture (OUTPUT HI and OUTPUT LO). Also, the appropriate jumpers between the test fixture signal panel and the component test module must be installed.

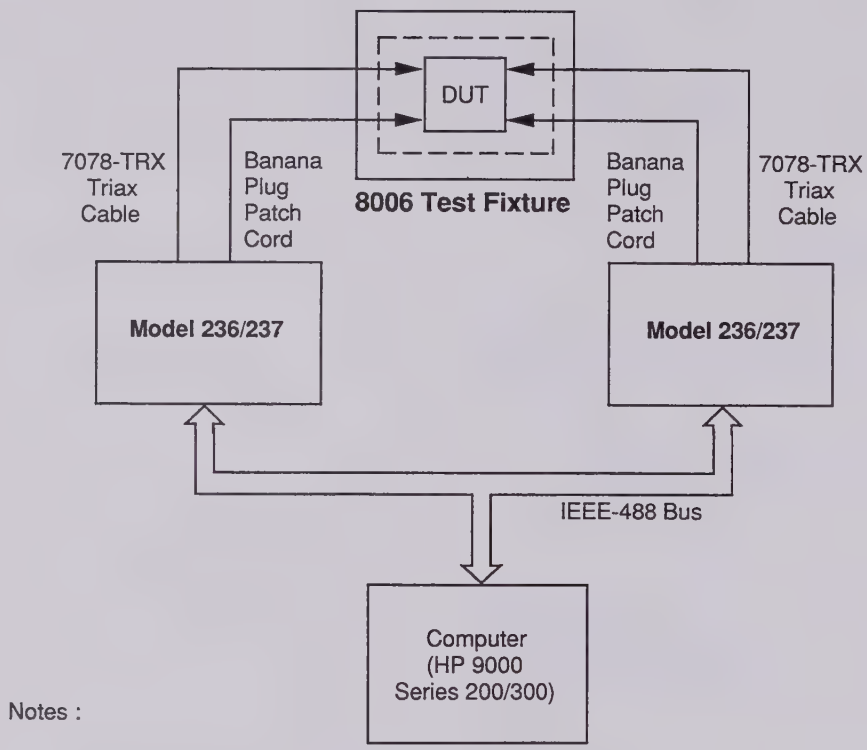
To optimize accuracy, you should use remote sensing in any of the applications (remote sensing is recommended for optimum accuracy with currents above 1mA). To use remote sensing, connect SENSE HI and SENSE LO to the test fixture, and add the necessary jumpers to the DUT. With this configuration, SENSE HI appears on the center conductor of the corresponding triax cable, and SENSE LO appears on the center conductor of the OUTPUT/SENSE LO triax cable. See Section 2 of the Model 236/237 Operator's Manual for complete details on test connections.

WARNING

When a Model 236/237 is programmed for remote sensing, hazardous voltage may be present on the SENSE and OUTPUT terminals when the unit is in operate regardless of the programmed voltage or current. To avoid a possible shock hazard, always turn off all power before connecting or disconnecting cables to the Source Measure Unit or the associated test fixture.

In addition to the different connecting scheme, you must modify the corresponding program by changing the "O0X" command string (local sensing) to "O1X" (local sensing). For example, the command string,

```
OUTPUT 716; "O0X"       ! Local sensing
```



Notes :

1. One unit required for 2-terminal tests.
2. Three units required for substrate bias with 3-terminal devices.

Figure 1-1. Typical System Configuration for Applications

should be changed to:

```
OUTPUT 716; "O1X"        ! Remote sensing
```

1.3 SOFTWARE CONFIGURATION

1.3.1 Programming Language

All the programming examples in this manual are written in Hewlett-Packard BASIC 4.0 (upward-compatible versions such as BASIC 5.0 or 5.1 can also be used). This programming language was chosen for these examples for two reasons: (1) its easy-to-understand syntax, and (2) its versatility in controlling the IEEE-488 bus. In addition to BASIC, you must have the proper binaries (including graphics binaries) loaded into the computer. See the computer documentation for complete details.

1.3.2 Example Programs

Table 1-1 summarizes the example programs included in this manual. Note that recommended devices are also summarized in this table. Program modification will probably be required for devices with different characteristics.

Keep in mind that these example programs are presented only as examples, and they may not suit your particular applications. Also, a limited amount of error checking is incorporated into the programs, so care should be taken not to damage any device being tested. However, hopefully many of these example programs will serve as a base or model toward other more complex, applications-specific programs.

WARNING

Modifying the example programs to allow voltages greater than ±42V may create a

shock hazard. Connect interlock circuits before use, and connect the fixture ⏚ screw to safety earth ground using #18 AWG minimum wire before using the programs.

Those who wish to run these programs but do not want to bother typing them in may obtain a diskette from the Keithley Instruments, Inc. Applications Department.

1.3.3 Graphics Routines

Graphics routines incorporated into many of the programs will plot simple graphs on the computer screen. You can modify the program to generate hard copy graphs on an HPGL plotter instead by changing the PLOTTER IS CRT, "INTERNAL" statement to read PLOTTER IS 705,"HPGL". Those with a bit-mapped graphics compatible printer can also dump graphics plots to the printer by using the DUMP GRAPHICS command, or use the corresponding computer key on those keyboards so equipped.

Table 1-1. Example Program Summary

Program #	Description	Recommended Device*	Paragraph
1	Voltage coefficient	10GΩ-100GΩ	2.4
2	Capacitor leakage	0.01-1μF	2.5
3**	Diode V_F vs. I	1N4148	2.6
4**	I_C vs. V_{CE} @ I_B	2N5089 NPN	3.4
5**	Gummel plot	2N5089 NPN	3.5
6A/6B	Dc current gain	2N5089 NPN	3.6
7	Differential gain	2N5089 NPN	3.6
8**	Transistor I_{CEO}	2N3904 NPN	3.7
9**	I_D vs. V_{DS} @ V_{GS}	2N4392 JFET	4.4
10	g_{fs} vs. V_{GS}	2N4392 JFET	4.5
11	g_{fs} vs. I_D	2N4392 JFET	4.5
12A/12B**	Threshold voltage, V_T	User defined	4.6
13	I_{SB} vs. V_{GS}	TG-51	5.4
14	Unit substrate bias	User defined	5.4
15	V source substrate bias (FET)	User defined	5.5
16	V source bias (bipolar)	User defined	5.5
17	Unit/current source	2N5089 NPN	6.2
18	Unit/electrometer	2N4392 JFET	6.3
19	Power transistors	MJE240	6.4
20	Scanner/Unit, multiple DUTs	2N5089 NPN	7.2
21	Resistivity using matrix	User defined	7.3
22	Unit/matrix switching system	User defined	7.4
23	Diode Test, Binary Transfer	1N4148	8.3
24	Common-emitter, Binary Transfer	2N5089	8.4
25	Self-bias threshold with plotting	Enhancement/depletion FET	8.5
26	Log sweep threshold with plotting	Enhancement/depletion FET	8.5

* Devices recommended for use with example programs as written. Program modification may be required for use with DUTs having different characteristics.
** IBM-PC/QuickBASIC versions of these programs are discussed in Appendix A.

1.3.4 Factory Initialization

As written, the example programs assume that each Source Measure Unit is configured for factory initialization parameters. To ensure that these programs run properly, it may be necessary to return each Source Measure Unit to the factory initialized conditions. To do so from the front panel, use the MENU button to SELECT FACTORY INIT. You can also modify each program to send a "J0X" command to each instrument at run time. This command should be placed immediately after the instrument is placed in remote, but before the unit is programmed for any other operating modes. An initialization command should be sent separately to each instrument. An example of a partial listing is shown below.

```
      ...
30    REMOTE 716              ! Put Unit #1 in remote
35    OUTPUT 716;"J0X"        ! Return Unit #1 to factory init.
40    OUTPUT 716;"F0,0X"      ! Source V, DC mode.
100   REMOTE 717              ! Put Unit #2 in remote.
105   OUTPUT 717;"J0X"        ! Return Unit #2 to factory init.
110   OUTPUT 717;"F1,1X"      ! Source I, sweep mode.
      ...
```

1.3.5 General Programming Considerations

The following paragraphs outline a number of factors to consider when using the example programs or when writing your own programs to perform various tests.

Ranging

When using autoranging measure with sweeps, it is better to program a sweep that will result in down-range changes because upranging causes the instrument to first go into compliance and then work its way down. Programming sweeps in this manner will result in faster sweeps, all other factors being equal. Some types of tests, however, may be subject to hysteresis and should be programmed to go only in one direction.

For a similar reason, the measurement range of a Source Measure Unit that is used only as a source should be programmed for a suitable fixed range to avoid autoranging that could slow down the overall measurement.

One-shot Triggering

When a Model 236/237 is in a one-shot trigger mode, it will not return to the bias value after a sweep until it receives another trigger stimulus. Most of the example programs do not include this trigger, so you might wish to add a line to the programs to do so. For example, if a unit is programmed for trigger on GET, the following typical programming line could be added to return the instrument to the bias condition:

```
455   TRIGGER 716
```

Line Cycle Integration

Many examples program the units for line cycle integration using the "S2" command, which assumes that the instrument is being used on a 60Hz power line frequency. Those who are using the units on 50Hz should change any "S2" commands to "S3", which will correctly program the instrument for 50Hz line cycle integration.

When Is My Sweep Finished?

The best way to determine when a sweep is done is to program the instrument to generate an SRQ on sweep done, and then wait for the SRQ to occur. This is the method used by most of the example programs in this manual. Instead of using this method, you could also simply test the sweep done bit in the status byte by repeatedly serial polling the unit, as in the code fragment example below.

```
200   S = SPOLL (716)              ! Serial poll unit.
210   IF NOT BIT(S,1) THEN 200     ! Sweep done?
```

Note also that it is not necessary to wait for the sweep to finish before you begin requesting data. Simply begin asking for data immediately after triggering the sweep; each bit of data will be sent when it becomes available (Program 5, in fact, demonstrates this technique). Note, however, that you may run into a bus timeout error, depending on the programmed delay time and the controller you are using.

How Big is My Sweep?

In order to make each example program as simple as possible, the sweep size and thus the data arrays are fixed. In a practical test program, however, you probably will want the capability of automatically sizing your sweeps. This can be done with the help of the U8 command,

which returns the number of source points in the sweep. The returned value could then be used to dimension any arrays and to size loop counters. The example code fragment below shows how to obtain the sweep size status word from the instrument.

```
300     OUTPUT 716;"U8X"        ! Request status
                                  word.
310     ENTER 716;A$            ! Input status word.
320     N=VAL(A$[4, 7])         ! Convert to nu-
                                  meric.
```

Bias Value Programming with Sweeps

The bias value appears at the output both prior to and after a sweep. In order to ensure that your DUT is properly biased before and after a sweep, you may wish to add a bias voltage programming command to certain programs. For example, assume that you wish to add a 0V bias programming command to one of the programs. The following syntax would be used:

```
120     OUTPUT 716;"B0, 0, 0X"  ! Program 0V bias,
                                  autorange, 0 delay
```

SECTION 2
Two-terminal Device Tests

2.1 INTRODUCTION

Two-terminal device tests discussed in this section include: voltage coefficient tests on resistors, leakage tests on capacitors, and diode characterization.

2.2 INSTRUMENT CONNECTIONS

Figure 2-1 shows the instrument connections for two-terminal device tests. Note that only one Source Measure Unit is required for these applications. Model 7078-TRX-3 triax cables are used to make triax connections, while banana plug patch cords can be used for binding post connections.

WARNING

Lethal voltages may be present when the test fixture lid is open. To avoid a possible shock hazard, the safety interlock circuit must be connected before use as shown in Figure 2-1.

Also, connect the test fixture ⏚ screw to safety earth ground using #18 AWG wire minimum before use. Turn off all power before connecting or disconnecting wires or cables.

NOTES

1. Remote sensing connections are recommended for optimum accuracy. See paragraph 1.2.1 for details.
2. If measurement noise is a problem, or for critical, low-level applications, use shielded cable for all signal connections.
3. When using the Model 8002A, place the Picoammeter/Source-Measure switch in the Source-Measure position.

2.3 JUMPER INSTALLATION

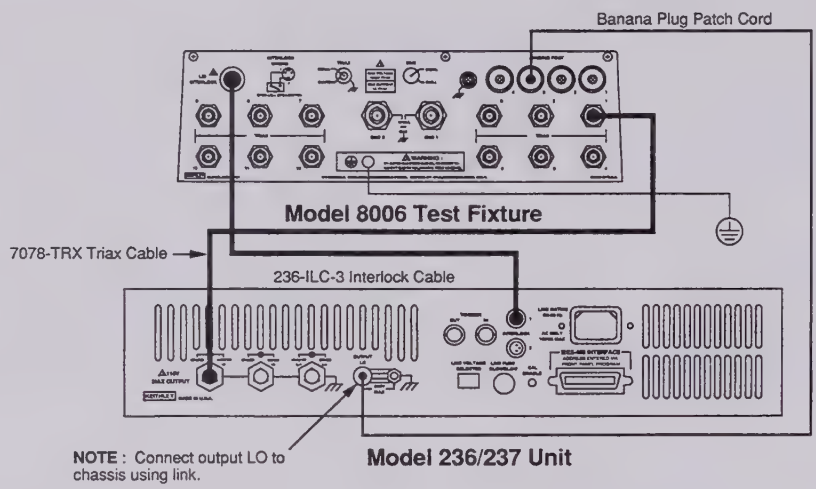
In order to complete connections to the device under test, Model 8006 Test Fixture jumpers must be installed, as shown in Figure 2-2. Note that local sensing is used in these applications, so one set of jumpers to the device socket is necessary.

2.4 VOLTAGE COEFFICIENT TESTS OF RESISTORS

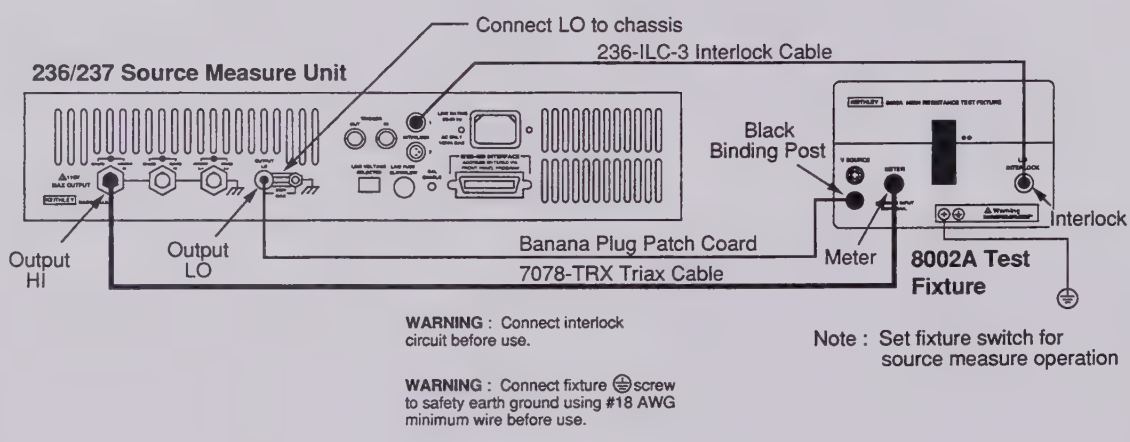
Resistors often show a change in resistance with applied voltage with high-megohm resistors (>$10^9\Omega$) showing the most pronounced effects. This change in resistance can be characterized as the voltage coefficient. The following paragraphs discuss voltage coefficient tests using a Model 236/237 Source Measure Unit.

2.4.1 Test Configuration

The test configuration for voltage coefficient measurements is shown in Figure 2-3. The Source Measure Unit sources the voltage across the resistor under test, and the picoammeter section measures the resulting current through the resistor.

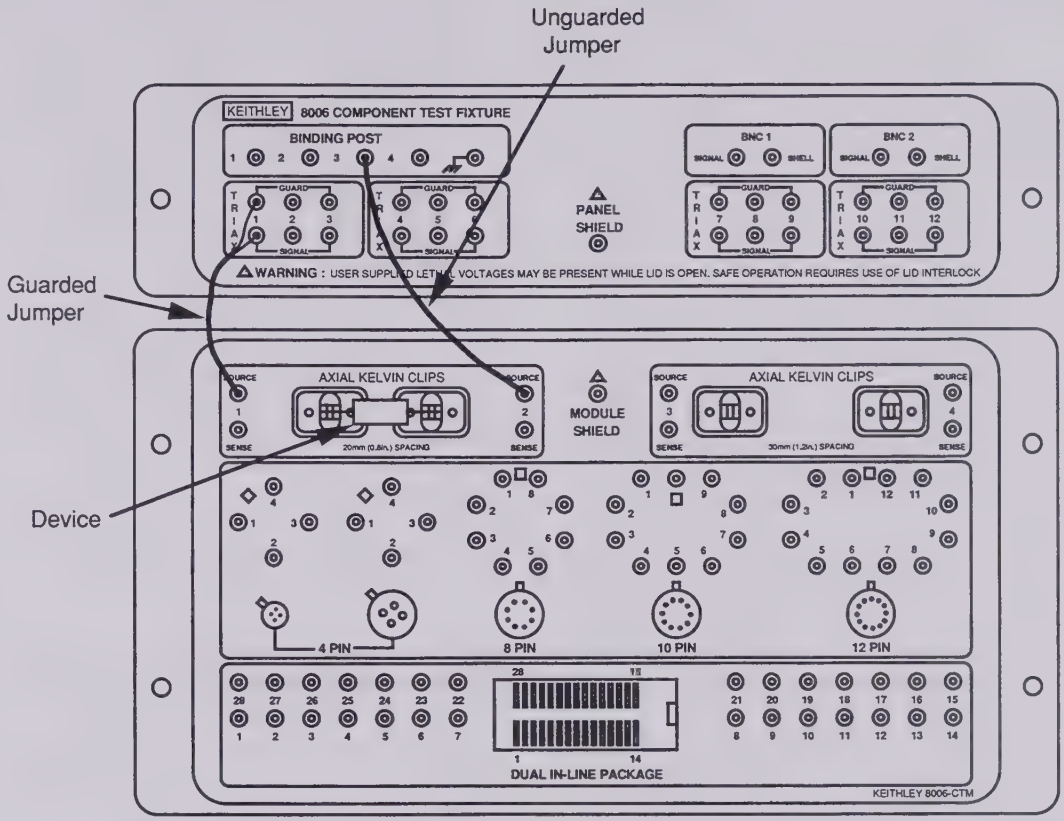

Banana Plug Patch Cord
Model 8006 Test Fixture
7078-TRX Triax Cable
236-ILC-3 Interlock Cable
NOTE : Connect output LO to chassis using link.
Model 236/237 Unit

A. Model 8006 Test Fixture


Connect LO to chassis
236-ILC-3 Interlock Cable
236/237 Source Measure Unit
Black Binding Post
Interlock
Output HI
Output LO
Banana Plug Patch Coard
7078-TRX Triax Cable
Meter
8002A Test Fixture
WARNING : Connect interlock circuit before use.
WARNING : Connect fixture ⏚ screw to safety earth ground using #18 AWG minimum wire before use.
Note : Set fixture switch for source measure operation

B. Model 8002A Test Fixture Connections

Figure 2-1. Instrument Connections for Two-terminal Device Tests



Model 8006 Test Fixture

Figure 2-2. Jumper Installation for Two-terminal Device Tests

2.4.2 Voltage Coefficient Calculations

Two different current readings at two different voltage values are required to calculate the voltage coefficient. Two resistance readings, R_1 and R_2, are then obtained, and the voltage coefficient in %/V can then be calculated as follows:

$$\text{Voltage Coefficient (\% /V)} = \frac{100\,(R_2 - R_1)}{R_1\,(V_2 - V_1)}$$

Where: R_1 = resistance calculated with first applied voltage (V_1).
R_2 = resistance calculated with second applied voltage (V_2).

For example, assume that the following values are obtained:

$$R_1 = 1.01 \times 10^{10}\,\Omega$$
$$R_2 = 1. \times 10^{10}\,\Omega$$
$$(V_2 - V_1) = 10V$$

The voltage coefficient is:

$$\text{Voltage Coefficient (\% /V)} = \frac{100\,(1 \times 10^8)}{1 \times 10^{10}\,(10)} = 0.1\%\,/V$$

2.4.3 Measurement Considerations

A couple of points should be noted when using this procedure to determine the voltage coefficient of high-megohm resistors. Keep in mind that any leakage resistance in the test system will degrade the accuracy of your measurements. To avoid such problems, use only a high-quality test fixture such as the Model 8002A or 8006. Also, make certain that the test fixture sockets are kept clean and free of contamination.

In addition, there is an upper limit on the resistance value that can be measured using this test configuration. For one thing, the test fixture has a finite (although very high) path isolation value. Secondly, the maximum resistance is determined by the test voltage and current-measurement resolution of the test instrument. Finally, the instrument has a typical output impedance of $10^{15}\Omega$.To maximize measurement accuracy with a given resistor, use the highest test voltages possible.

2.4.4 Example Program 1: Voltage Coefficient Test

Program 1 below demonstrates programming techniques for voltage coefficient tests. Follow the steps below to use the test program.

1. With the power off, connect the Model 236 to the IEEE-488 interface of the computer.
2. Connect the test fixture to the Source Measure Unit using appropriate cables (see Figure 2-1).
3. Turn on the Model 236, and allow the unit to warm up for two hours for rated accuracy. Make sure the primary address of the unit is set to 16.
4. Turn on the computer, and boot up BASIC.

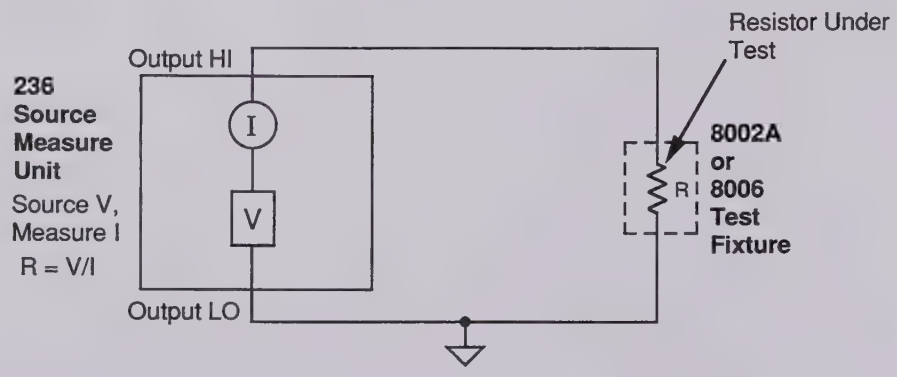


Figure 2-3. Voltage Coefficient Test Configuration

5. Enter the lines below into the computer.
6. Install the resistor being tested in the appropriate axial component socket of the test fixture, then close the test fixture lid.
7. RUN the program, then enter the required values when prompted to do so. You will be prompted to input two voltage values and a delay value. The two voltage values are the test voltages, and the delay value is the time between source on and measure.
8. The computer will then program the unit and measure the currents through the resistor. The calculated voltage coefficient and two resistance values will then be displayed on the CRT. If the unit is over compliance, or if the test fixture lid is open, an error message will be displayed.

2.4.5 Typical Program 1 Results

The actual voltage coefficient you obtain using the program will, of course, depend on the resistor being tested. Typical voltage coefficient obtained for a 10GΩ resistor (Keithley part number R-319-10G) was about 8ppm/V (.008%/V).

2.4.6 Program 1 Description

For the following description, refer to the program below and the program flowchart, which is shown in Figure 2-4.

At the start of the program, a device clear is sent to the Source Measure Unit to return the unit to default state (line 20), and the unit is then placed in remote (line 30). After the screen is cleared (line 40), the Source Measure Unit is programmed as follows (lines 50-90):

- Source V, dc mode
- Local sense, trigger on GET
- 100mA compliance, autorange measure
- Data format to output measure data only with no prefix
- Line cycle integration, 32 reading filter (to minimize noise)

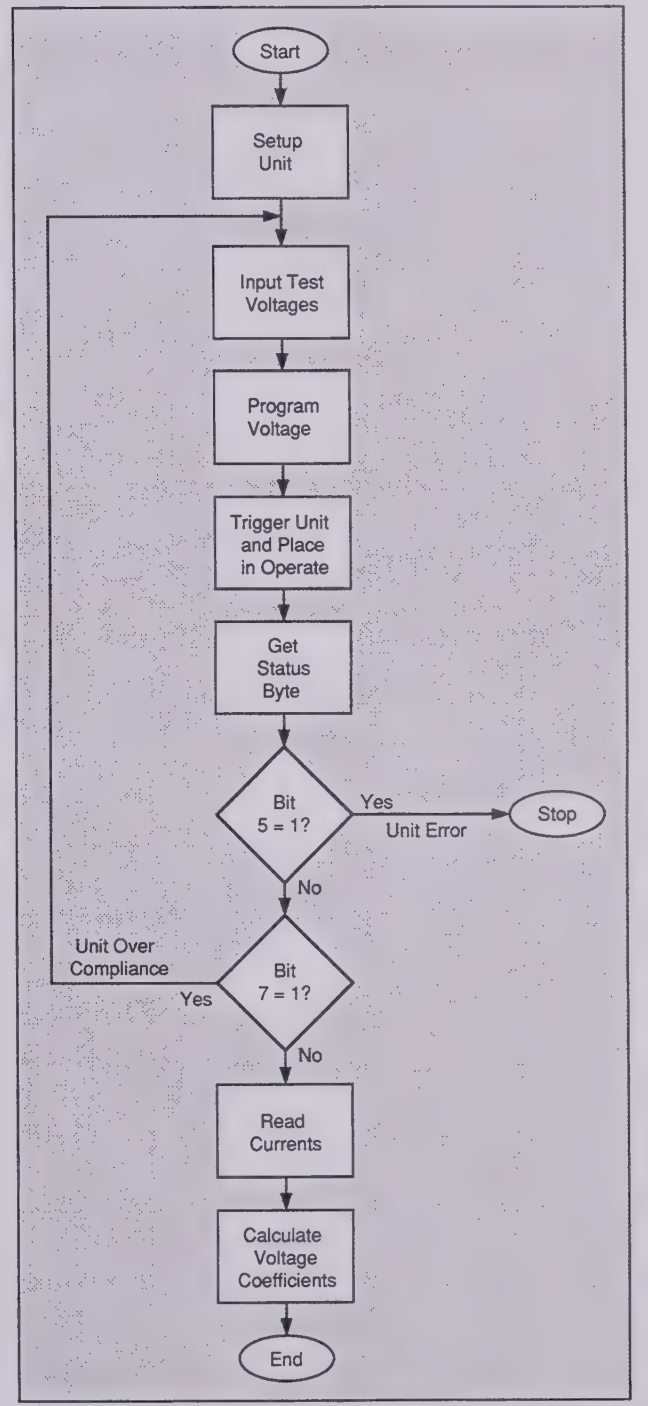


Figure 2-4. Program 1 Flowchart

After the unit is setup, the operator is then prompted to input the two test voltage values and the delay value (lines 90-150). Note that the voltage inputs are tested to verify that they are within the required 100V limits. After these inputs, the unit is programmed for the first source value (line 150), and the operator is then prompted to close the test fixture (line 160).

Once the operator signals to continue, the unit trigger is armed, and the unit is placed into operate (line 190). The status byte is then requested and checked to determine if the lid interlock is open (lines 210-250). If so, a message is displayed, and the program halts.

The unit is then triggered (lines 270). After the programmed delay period (line 280), the status byte is requested, and bit 7 of the status byte is checked (line 300) to determine if the unit is over compliance. If so, the program loops back to allow the operator to input different voltage source values.

Assuming that all goes well, a current reading is then requested from the unit (line 350), and the second voltage is programmed (line 360). The second current reading is then obtained (line 370), and the resistance values and voltage coefficient are then calculated and displayed (lines 390-440).

```
10    REM  RESISTOR VOLTAGE COEFFICIENT TEST PROGRAM REV. 1.3 (Program 1)
20    CLEAR 7                              ! Clear 236
21    DIM Err$[50]                         ! Dimension error string
30    REMOTE 716                           ! Put 236 in remote
40    OUTPUT KBD;CHR$(255);CHR$(75);       ! Clear screen
50    OUTPUT 716;"F0,0X"                   ! Source V, DC mode
60    OUTPUT 716;"O0T1,0,0,0X"             ! Local sense, trigger on GET
70    OUTPUT 716;"L100E-3,0X"              ! 100mA compliance, autorange measure
80    OUTPUT 716;"G4,2,0X"                 ! Output measure,no prefix,DC
90    OUTPUT 716;"S2P5M128,0X"             ! Line cycle, 32 reading filter,SRQ
100   INPUT "Enter voltage V1 (0-100)",V1 ! Input first voltage
110   IF ABS(V1)>100 THEN 100              ! Check V1 limits
120   INPUT "Enter voltage V2",V2          ! Input second voltage
130   IF ABS(V2)>100 THEN 120              ! Check V2 limits
140   INPUT "Enter source-measure delay (0-65000msec)",Dly ! Input delay
150   OUTPUT 716;"B";V1;",0,";Dly;"X"      ! Program source and delay
160   PRINT "Close test fixture lid then press CONT to begin test"
170   PAUSE
180   OUTPUT 716;"R1Z0X"                   ! Arm trigger,suppress off
190   OUTPUT 716;"N1X"                     ! Turn on 236 output
200   WAIT .1                              ! Wait 0.1sec
210   Stat=SPOLL(716)                      ! Serial poll 236
220   IF BIT(Stat,5) THEN                  ! Check for 236 error
230   PRINT "236/237 error"
240   BEEP
241   WAIT 2                               ! Wait for error to clear
243   OUTPUT 716;"U1X"                     ! Request U1 word to clear error
244   ENTER 716;Err$                       ! Input error word
250   STOP
260   END IF
270   TRIGGER 716                          ! Trigger 236
280   WAIT Dly/1000+1                      ! Wait
290   Stat=SPOLL(716)                      ! Serial poll 236
300   IF BIT(Stat,7) THEN                  ! Check for over compliance
310   PRINT "236 over compliance"
320   BEEP
330   GOTO 100
340   END IF
350   ENTER 716;I1                         ! Get first current reading
360   OUTPUT 716;"B";V2;",0,";Dly;"X"      ! Program V2 Voltage
370   ENTER 716;I2                         ! Get second current reading
380   OUTPUT 716;"N0X"                     ! Turn off 236 output
390   R1=V1/I1                             ! Compute R1
400   R2=V2/I2                             ! Compute R2
410   Coeff=100*(R2-R1)/(R1*(V2-V1))       ! Compute voltage coefficient
420   PRINT "COEFFICIENT=";Coeff;"%/V"     ! Display voltage coefficient
430   PRINT "RESISTANCE R1=";R1            ! Display resistance values
440   PRINT "RESISTANCE R2=";R2
450   END
```

2.5 CAPACITOR LEAKAGE TEST

One important parameter associated with capacitors is leakage current. Once the leakage current is known, the insulation resistance can be easily calculated. The amount of leakage current in a capacitor depends both on the type of dielectric as well as the applied voltage. With a test voltage of 100V, for example, ceramic dielectric capacitors have typical leakage currents in the nA to pA range, while polystyrene and polyester dielectric capacitors exhibit a much lower leakage current--typically in the fA (10^{-15}A) range

2.5.1 Test Configuration

Figure 2-5 shows the test configuration for the capacitor leakage test. The Model 236/237 Source Measure Unit sources the test voltage across the capacitor, and it measures the resulting leakage current through the device. The resistor, R, is included for current limiting, and it also helps to reduce noise. A typical value for R is 1MΩ, although that value can be decreased for larger capacitor values. Note, however, that values under 10kΩ are not recommended.

2.5.2 Leakage Resistance Calculations

Once the leakage current is known, the leakage resistance can easily be calculated from the applied voltage and leakage current value as follows:

$$R = V/I$$

For example, assume that you measured a leakage current of 25nA with a test voltage of 100V. The leakage resistance is simply:

$$R = 100/25nA = 4G\Omega\ (4\times 10^{9}\Omega)$$

2.5.3 Measurement Considerations

After the voltage is applied to the capacitor, the device must be allowed to charge fully before the current measurement can be made. Otherwise, an erroneous current, with a much higher value, will be measured. The time period during which the capacitor charges is often termed the "soak" time. A typical soak time is seven time constants, or 7RC, which would allow settling to less than 0.1% of final value. For example, if R is 1MΩ, and C is 1μF, the recommended soak time is seven seconds. With small leakage currents (<1nA), it may be necessary to use a fixed measurement range instead of autoranging.

2.5.4 Example Test Program 2: Capacitor Leakage Test

Program 2 below performs the capacitor leakage test described above. Follow the steps below to run the test using this program.

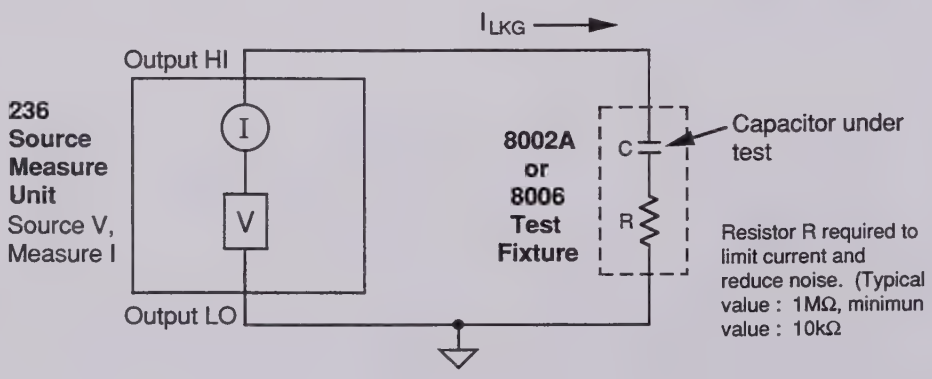


Figure 2-5. Test Configuration for Capacitor Leakage Test

WARNING

Hazardous voltage may be present on the capacitor leads after running this test. Discharge the capacitor before removing it from the test fixture.

1. With the power off, connect the Model 236 to the IEEE-488 interface of the computer.
2. Connect the test fixture to the Source Measure Unit using appropriate cables (see Figure 2-1).
3. Turn on the Model 236, and allow the unit to warm up for two hours for rated accuracy. Make sure the primary address of the unit is set to 16.
4. Turn on the computer, and boot up BASIC.
5. Enter the lines below into the computer.
6. Discharge and install the capacitor being tested along with the series resistor in the appropriate axial component sockets of the test fixture. Install the necessary jumpers, then close the test fixture lid.

NOTE

The capacitor should be fully discharged before running the test.

7. RUN the program, then enter the required values when prompted to do so. You will be prompted to input the test voltage and soak time values. When entering the soak time, choose a value of at least 7RC to allow settling to within 0.1% of final value. At very low currents (<500fA), a longer settling time may be required to compensate for dielectric absorption, especially at high voltages.
8. The computer will then program the unit and then wait the programmed soak time as a delay time for settling. After settling, any offset current will be suppressed, and the Model 236 will be programmed for the test voltage value. After the soak time has passed, the computer will measure the leakage current, and then display the leakage current and calculate and display the leakage resistance. If the unit is over compliance, or if the test fixture lid is open, an error message will be displayed.

2.5.5 Typical Program 2 Results

As pointed out earlier, the exact value of leakage current will depend on the capacitor value as well as the dielectric. A typical value obtained for a 1μF aluminum electrolytic capacitor was about 80nA at 25V.

2.5.6 Program 2 Description

Refer to the program listing below and the flowchart in Figure 2-6 for the following program description,

After the unit is cleared and placed in remote (lines 20 and 30), the unit is programmed as follows (lines 50-90):

- Source V, dc mode
- Local sense, trigger on GET, continuous
- 10mA compliance, autorange measure
- Measure only data format, no prefix, dc data
- Line cycle integration, 32-reading filter (to minimize noise)

After initial setup of the Model 236, the operator is then prompted to input the desired test voltage (line 100) and the voltage limit is checked (line 110). Next, the desired settling/soak time is requested, and the operator is prompted for a signal to begin the test (lines 120-140); and the output is programmed to 0V (line 150). After the operator signal, the trigger is armed, and the unit is placed in operate (lines 160 and 170). The status byte is then requested after a 0.1sec delay period (lines 180 and 190), and the byte is checked to see if the test fixture lid is open (lines 200-240). If the lid is open, a message to that effect is displayed, and the program halts.

The unit is then triggered (line 250), and the computer then waits the programmed delay time to allow the circuit to settle (line 260). Suppress is then enabled to zero out any offset current in the test system (line 280). The computer then programs the test voltage and then waits the programmed soak time to allow the capacitor to charge fully (lines 290 and 300). Once the soak time has elapsed, the status byte is obtained, and a check for an over-compliance condition is made (lines 350-360). If an over-compliance condition is noted (flagged by status byte bit 7), the program loops back to allow the operator to input a new voltage value.

If no errors occur, a current reading is requested from the unit (line 380), and the current and calculated leakage resistance are then displayed (lines 400 and 410).

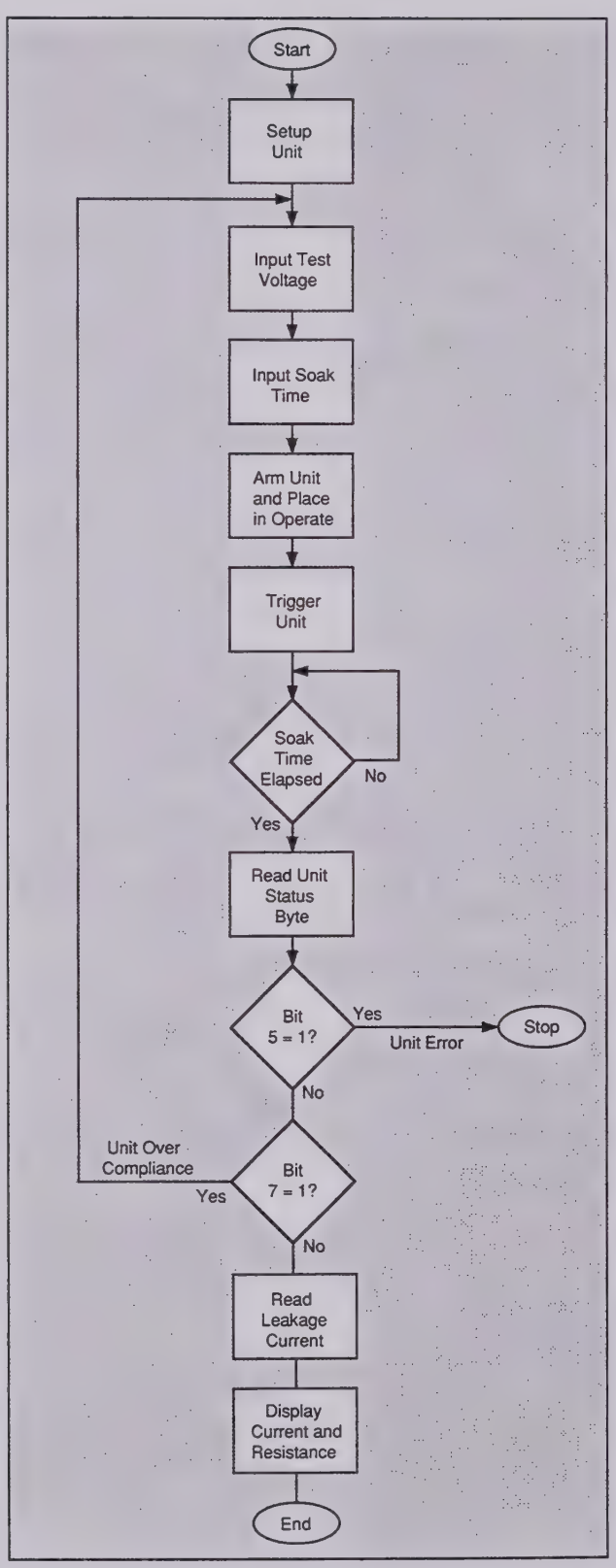


Figure 2-6. Program 2 Flowchart

```
10    REM  CAPACITOR LEAKAGE TEST PROGRAM REV. 1.3 (Program 2)
11    DIM Err$[50]                          ! Dimension error string
20    CLEAR 7                               ! Clear 236
30    REMOTE 716                            ! Put 236 in remote
40    OUTPUT KBD;CHR$(255);CHR$(75);        ! Clear screen
50    OUTPUT 716;"F0,0X"                    ! Source V, DC mode
60    OUTPUT 716;"O0T1,0,0,0X"              ! Local sense, trigger on GET
70    OUTPUT 716;"L10E-3,0X"                ! 10mA compliance, autorange measure
80    OUTPUT 716;"G4,2,0X"                  ! Output measure,no prefix,DC
90    OUTPUT 716;"S2P5M128,0X"              ! Line cycle, 32 reading filter,SRQ
100   INPUT "Enter test voltage (0-100)",V ! Input test voltage
110   IF ABS(V)>100 THEN 100                ! Check V limits
120   INPUT "Enter settling and soak time (seconds)",W ! Input time
130   PRINT "Close test fixture lid then press CONT to begin test"
140   PAUSE
150   OUTPUT 716;"B0,0,0X"                  ! Program 0V
160   OUTPUT 716;"R1Z0X"                    ! Arm trigger,suppress off
170   OUTPUT 716;"N1X"                      ! Turn on 236 output
180   WAIT .1                               ! Wait 0.1sec
190   Stat=SPOLL(716)                       ! Serial poll 236
200   IF BIT(Stat,5) THEN                   ! Check for 236 error
210   BEEP
220   PRINT "236/237 error"
221   WAIT 2                                ! Wait for error to clear
222   OUTPUT 716;"U1X"                      ! Request U1 word to clear error
223   ENTER 716;Err$                        ! Input error word
230   STOP
240   END IF
250   TRIGGER 716                           ! Trigger 236
260   PRINT "Waiting";W;"seconds for settling time"
270   WAIT W
280   OUTPUT 716;"Z1X"                      ! Enable suppress
285   WAIT 2                                ! Wait for suppress
290   PRINT "Waiting";W;"seconds for soak time"
300   OUTPUT 716;"B";V;",0,0X"              ! Program DC voltage
310   WAIT W+1                              ! Wait soak time
320   Stat=SPOLL(716)                       ! Serial poll 236
330   IF BIT(Stat,7) THEN                   ! Check for over compliance
340   PRINT "236 over compliance."
350   BEEP
360   GOTO 100
370   END IF
380   ENTER 716;I                           ! Get 236 current reading
390   OUTPUT 716;"N0X"                      ! Turn off 236 output
400   PRINT "Leakage current=";I            ! Display leakage current
410   PRINT "Leakage resistance=";V/I       ! Display leakage resistance
420   END
```

2.6 DIODE CHARACTERIZATION

The Model 236 is an ideal instrument to characterize diodes because it can source a current through the device, and measure the resulting forward voltage drop, V_F, across the device. The following paragraphs discuss the test configuration and give a sample test program for such tests.

2.6.1 Test Configuration

Figure 2-7 shows the test configuration for the diode characterization test. The Model 236 is used to source the forward current, I_F, through the diode under test, and it also measures the forward voltage, V_F, across the device. I_F is swept across the desired range of values, and V_F is measured at each current. Note that the same general configuration could be used to measure leakage current by reversing the diode, sourcing voltage, and measuring the leakage current.

2.6.2 Measurement Considerations

Since the voltages being measured will be fairly small (≈0.6V), remote sensing can be used to minimize the effects of voltage drops across the test connections and in the test fixture. To use remote sensing with the Model 8006 install both sets of jumpers to the axial Kelvin socket to be used for the diode being tested, and modify the test program accordingly.

2.6.3 Example Program 3: Diode Characterization

Program 3 below demonstrates the basic programming techniques for running the diode characterization test. Follow the steps below to use this program.

1. With the power off, connect the Model 236 to the IEEE-488 interface of the computer.
2. Connect the test fixture to the unit using appropriate triax cables (see Figure 2-1).
3. Turn on the Model 236, and allow the unit to warm up for two hours for rated accuracy. Make sure the primary address of the unit is set to 16.
4. Turn on the computer, and boot up BASIC.
5. Enter the lines below into the computer.
6. Install a small-signal silicon diode such as a 1N914 or 1N4148 in the appropriate axial socket of the test fixture. Be certain that the jumpers are properly installed, then close the test fixture lid.
7. RUN the program in the usual manner. The computer will program the Source Measure Unit and run the diode test using currents between 0μA and 100μA in 1μA increments using a fixed delay of 10msec.
8. Once the sweep has been completed, you will be prompted to press CONT to generate a plot of the data. A simple V_F vs. I_F plot will then be displayed on the computer CRT.
9. To return to BASIC from the graph, press CONT.

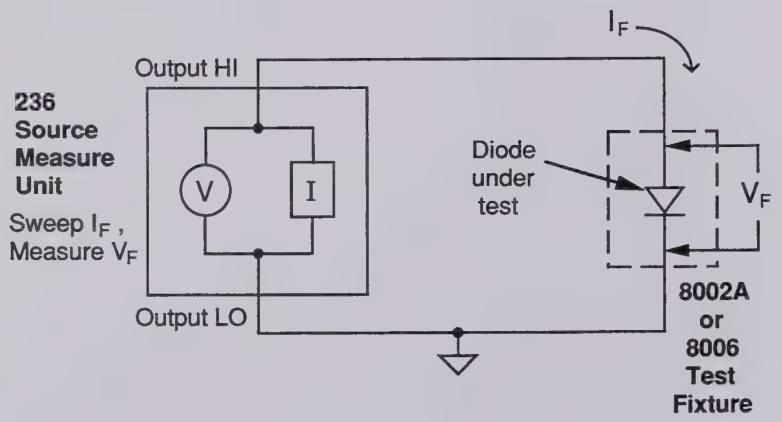


Figure 2-7. Diode Characterization Test Configuration

2.6.4 Typical Program 3 Results

Figure 2-8 shows typical results obtained using example Program 3. These results are for a 1N914 silicon diode.

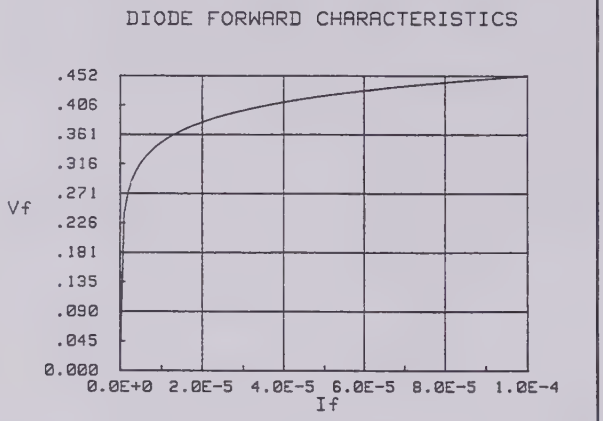


Figure 2-8. Example Diode Test Program Plot

2.6.5 Program 3 Description

For the following description, refer to the program listing and the flowchart shown in Figure 2-9.

Initially, the OPTION BASE statement is used to declare that all array subscripts begin with 1 rather than 0 (line 20), and the reading array is then dimensioned for 101 points with two readings each (line 30). Next, the unit is cleared and placed in remote (lines 40 and 50), and the instrument is initialized as follows (lines 70-160):

- Source I, sweep mode
- Local sense, continuous trigger on GET
- 10V compliance, autorange measure
- Source and measure data format with no prefix and sweep data output
- SRQ on sweep done
- Suppress on (nulls offsets)
- Istart: 0μA
- Istop: 100μA
- Istep: 1μA

After setup, the sweep is then programmed (line 170), and the operator is prompted to signal the start of the test (lines 180 and 190). Following the operator signal, the trigger is armed (line 200), and the unit is placed into operate and triggered (lines 210 and 220). Following the

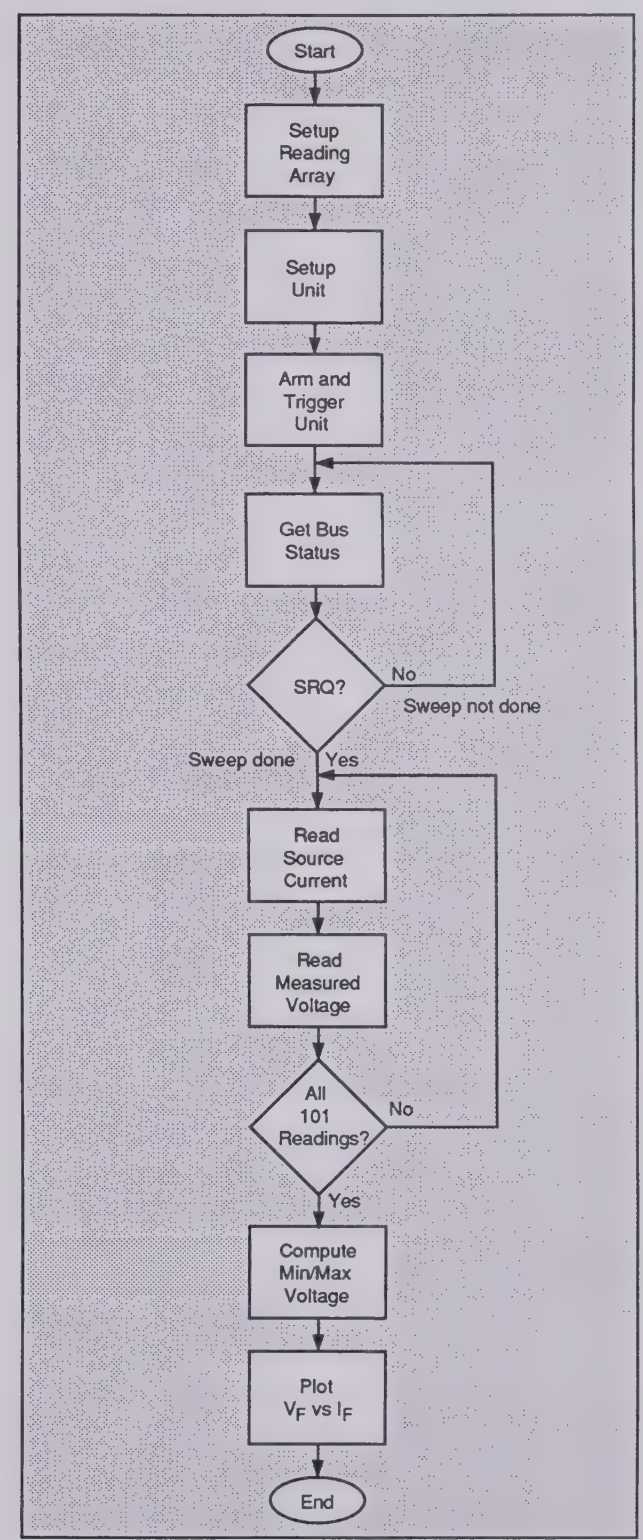


Figure 2-9. Program 3 Flowchart

trigger, the program enters a loop where it continuously checks the SRQ line on the bus to determine when the sweep is finished (lines 240 and 250).

When the unit finishes the sweep, it sets the SRQ line true, and the program falls out of the loop. The status byte is then read (line 260) to clear the SRQ, and the unit is placed in standby (line 270). Next, all 101 data points are requested from the computer (lines 280-300). Here, the source value, which is the forward current, is placed in element (I,1) of the reading array, and the measured voltage is placed in element (I,2) of the reading array. The minimum and maximum measured voltage values are then found (lines 310-360); these values are used to scale the Y axis of the plot.

The graphics routines are located in lines 410-670 of the program. Most of these are self-explanatory, but a few of them require comment. Note that the soft clip limits are defined by the VIEWPORT statement (line 500), while the X,Y scaling is performed by the WINDOW statement (line 510). Note that X axis scaling is determined by the programmed start and stop currents (Istart and Istop), while the Y axis limits (Ymin and Ymax) are the values determined from the minimum and maximum measured voltages. Finally, plotting is performed by the PLOT statement (line 560), which plots the entire reading array with one statement, and the axes are numbered (lines 570-670).

2.6.6 Modifying Program 3

As written, the program sets up the Source Measure Unit to step the current from 0μA to 100μA in 1μA increments. For other values, you can simply change the Istart, Istop, and Istep values in lines 130-150 to the required values, or (better yet), incorporate INPUT statements to allow operator input of those values. It may also be necessary to change the source range value from 6 (100μA range) to accommodate different current parameters.

If you choose values that result in a sweep length other than 101 points, additional modifications to the program will be necessary. The DIM statement declaration (line 30) and loop counter values (lines 280 and 330) must agree with the number of points in the sweep.

2.6.7 Using Log Sweeps

With some devices, it may be desirable to use a log sweep because of the wide range of currents necessary to perform the test. Program 3, for example, can be modified for a log sweep of the diode current by changing the Q1 command in line 170 to Q2 with appropriate parameters. For example, assume that you wish to sweep from 1μA to 100mA using a log sweep, the program lines would be modified as follows:

```
130  Istart=1E-6                ! Define 1μA start current
140  Istop=100E-3               ! Define 100mA stop current
150  Points=1                   ! Select 10 points per decade
170  OUTPUT 716;"Q2,";
     Istart;",";Istop;",";
     Points;",9,";Dly;"X"
```

Note that the start and stop currents are programmed just as before, although with a much wider range than would be practical with a linear sweep. With log sweep, however, the Points parameter, which defines the number of points per decade, replaces the Istep parameter that is used with the linear sweep. The source range is also changed to a value of 9 (100mA range).

2.6.8 Using Pulsed Sweeps

In some cases, it may be desirable to use a pulsed sweep to avoid device self-heating that could affect the test results. For example, Program 3 can be modified to use a staircase pulse sweep by substituting the Q4 command for the Q1 command along the correct parameters. For example, assume that you wish to step the current from 0μA to 100μA at 10μA increments with an on time of 10msec, and an off time of 90msec. The following lines would be added or substituted:

```
160  tON=10                     ! Define 10msec on time.
165  tOFF=90                    ! Define 90msec off time.
170  OUTPUT 716;"Q4,";
     Istart;",";Istop;",";
     Istep;",0,";tON;tOFF;
     "X"
```

The main difference between programming the standard staircase and pulsed staircase sweep is that on time and off time are substituted for the delay time.

```
10    REM  DIODE CHARACTERIZATION TEST PROGRAM REV. 1.3 (Program 3)
20    OPTION BASE 1                          ! First array subscript is 1
30    DIM Reading(101,2)                     ! Dimension reading array (101 pts.)
40    CLEAR 7                                ! Clear 236
50    REMOTE 716                             ! Put 236 in remote
60    OUTPUT KBD;CHR$(255);CHR$(75);         ! Clear screen
70    OUTPUT 716;"F1,1X"                     ! Source I, sweep mode
80    OUTPUT 716;"O0T1,0,0,0X"               ! Local sense, trigger on GET
90    OUTPUT 716;"L10,0X"                    ! 10V compliance, autorange measure
100   OUTPUT 716;"G5,2,1X"                   ! Source,measure,no prefix,sweep data
110   OUTPUT 716;"M2,X"                      ! SRQ on sweep done
115   OUTPUT 716;"B0,0,0X"                   ! Program 0 bias value
120   OUTPUT 716;"Z1X"                       ! Enable suppress
130   Istart=0                               ! Define 0uA start current
140   Istop=1.0E-4                           ! Define 100uA stop current
150   Istep=1.0E-6                           ! Define 1uA step current
160   Dly=10                                 ! Define 10msec delay value
170   OUTPUT 716;"Q1,";Istart;",";Istop;",";Istep;",0,";Dly;"X" !  Program sweep
180   PRINT "Close lid, press CONT to begin"
190   PAUSE                                  ! Wait to continue
200   OUTPUT 716;"R1X"                       ! Arm trigger
210   OUTPUT 716;"N1X"                       ! Turn on 236 output
220   TRIGGER 716                            ! Trigger 236 to start sweep
230   PRINT "Waiting for sweep to end"
240   STATUS 7,7;Stat                        ! Get IEEE-488 bus status
250   IF NOT BIT(Stat,10) THEN 240           ! Wait for SRQ on sweep done
260   Stat=SPOLL(716)                        ! Serial poll 236 to clear SRQ
270   OUTPUT 716;"N0X"                       ! Turn off 236 output
280   FOR I=1 TO 101                         ! Loop for all readings
290   ENTER 716;Reading(I,1),Reading(I,2)! Get 236 current and voltage readings
300   NEXT I                                 ! Loop back for next reading
310   Ymin=MAXREAL                           ! Find minimum and maximum voltage
320   Ymax=-MAXREAL
330   FOR I=1 TO 101
340   IF Reading(I,2)<Ymin THEN Ymin=Reading(I,2)
350   IF Reading(I,2)>Ymax THEN Ymax=Reading(I,2)
360   NEXT I
370   PRINT "Press CONT to display graph"
380   PRINT "Press CONT while in graph to return to BASIC"
390   PAUSE
400   OUTPUT KBD;CHR$(255);CHR$(75);         ! Clear CRT
410   GINIT                                  ! Initialize graphics
420   PLOTTER IS CRT,"INTERNAL"              ! Define plot to CRT
430   GRAPHICS ON                            ! Turn on graphics
440   MOVE 30,95                             ! Title graph
450   LABEL "DIODE FORWARD CHARACTERISTICS"
460   MOVE 70,10                             ! Label X axis
470   LABEL "If"
480   MOVE 5,53                              ! Label Y axis
490   LABEL "Vf"
500   VIEWPORT 30,120,20,85                  ! Define soft clip limits
```

```
510   WINDOW Istart,Istop,Ymin,Ymax       ! Scale graph
520   X1=(Istop-Istart)/10                ! Compute X axis increment
530   Y1=(Ymax-Ymin)/10                   ! Compute Y axis increment
540   GRID X1*2,Y1*2,Istart,Ymin          ! Draw grid
550   AXES X1,Y1,Istart,Ymin              ! Add some tick marks
560   PLOT Reading(*)                     ! Plot data
570   CSIZE 4                             ! Define character size
580   LORG 6                              ! Center characters
590   CLIP OFF                            ! Turn off soft clipping
600   FOR I=Istart TO Istop+.01*Istep STEP 2*X1 ! Number X axis
610   MOVE I,Ymin-(Y1/4)
620   LABEL USING "#,D.DESZ";I
630   NEXT I
640   FOR I=Ymin TO Ymax+.01*Y1 STEP Y1   ! Number Y axis
650   MOVE Istart-(1.3*X1),I+(.3*Y1)
660   LABEL USING "#,MDD.DDD";I
670   NEXT I
680   PAUSE
690   OUTPUT KBD;CHR$(255);CHR$(75);      ! Turn off alpha display
700   GRAPHICS OFF                        ! Turn off graphics display
710   END
```

SECTION 3
Bipolar Transistor Tests

3.1 INTRODUCTION

Bipolar transistor tests discussed in this section include: tests to generate common-emitter characteristic curves, Gummel plot, current gain, and transistor leakage tests.

3.2 INSTRUMENT CONNECTIONS

Figure 3-1 shows the instrument connections for the bipolar transistor tests outlined in this section. Two Model 236/237 Source Measure Units are required for the tests (except for the leakage current test, which requires only one Source Measure Unit). In addition, the Model 8006 test fixture is recommended to make connections to the transistor under test.

Model 7078-TRX-3 triax cables are recommended to make instrument-to-test fixture connections. In addition, the safety interlock connecting cables must be connected as shown.

WARNING
Lethal voltages may be exposed when the test fixture lid is open. To avoid a possible

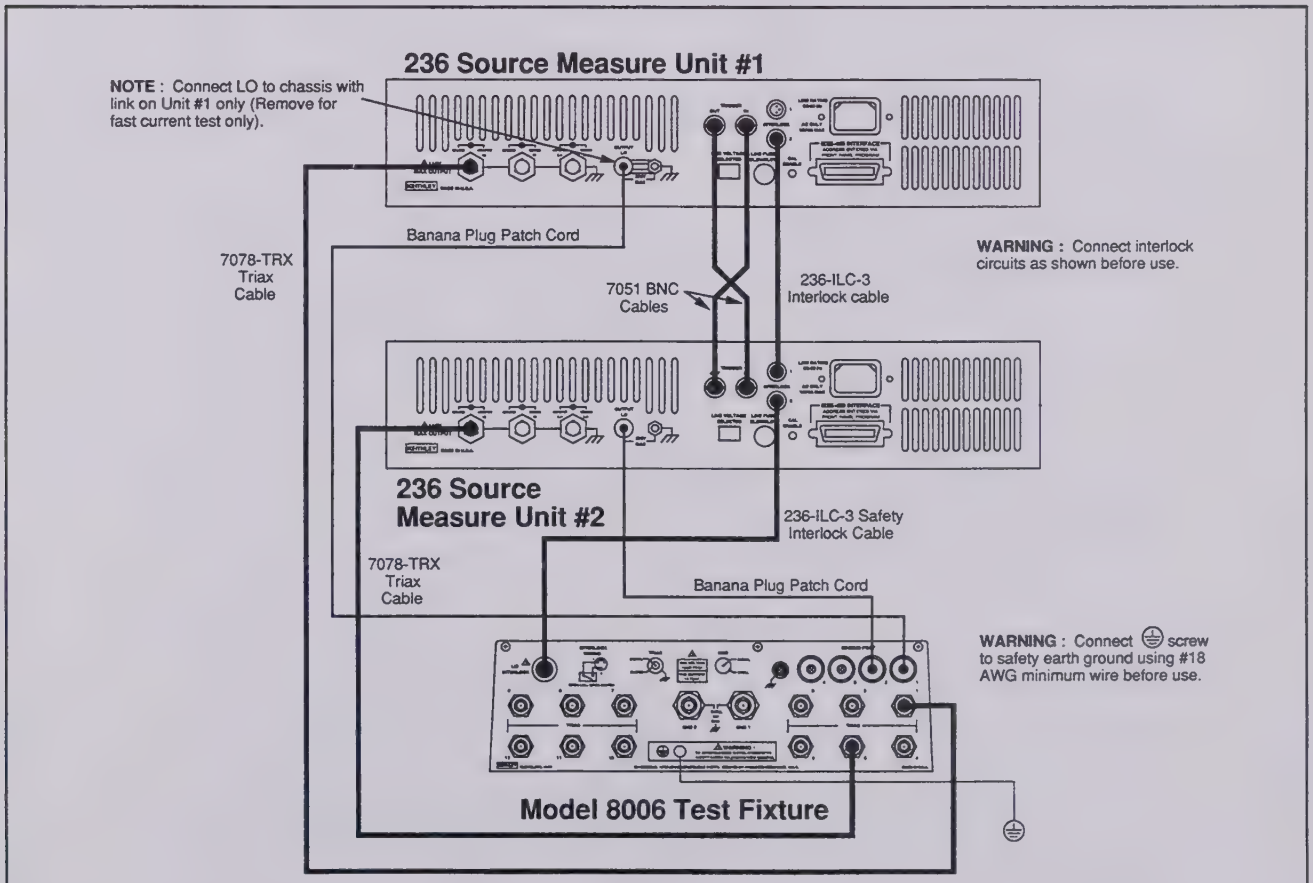

236 Source Measure Unit #1
NOTE : Connect LO to chassis with link on Unit #1 only (Remove for fast current test only).
Banana Plug Patch Cord
7078-TRX Triax Cable
7051 BNC Cables
236-ILC-3 Interlock cable
WARNING : Connect interlock circuits as shown before use.
236 Source Measure Unit #2
236-ILC-3 Safety Interlock Cable
7078-TRX Triax Cable
Banana Plug Patch Cord
WARNING : Connect ⏚ screw to safety earth ground using #18 AWG minimum wire before use.
Model 8006 Test Fixture

Figure 3-1. Instrument Connections for Transistor Tests

shock hazard, the safety interlock circuit must be connected as shown in Figure 3-1 before use. Connect fixture ⏚ screw to safety earth ground using #18 AWG minimum wire before use. Turn off all power before connecting or disconnecting wires or cables.

Two final connections that must be made are the Source Measure Unit trigger connections. Connect the TRIGGER OUT jack of Unit #1 to the TRIGGER IN jack of Unit #2, and connect the TRIGGER OUT jack of Unit #2 to the TRIGGER IN jack of Unit #1. Use standard BNC-to-BNC cables such as the Model 7051 to make these connections.

NOTES

1. Remote sensing connections are recommended for optimum accuracy. See paragraph 1.2.2 for details.
2. If measurement noise is a problem, or for critical, low-level applications, use shielded cable for all signal connections.
3. Most of the transistor test programs use external triggering. If the trigger jacks are not connected as shown, the programs will not function properly.

3.3 JUMPER INSTALLATION FOR TRANSISTOR TESTS

Figure 3-2 shows jumper installation for the transistor tests. The DUT itself should be placed in the appropriate four-terminal TO package socket, and the jumper connections should be made between the instrument panel jacks and the jacks on the component panel. Note that local sensing is used for most applications, so jumpers should be connected as shown.

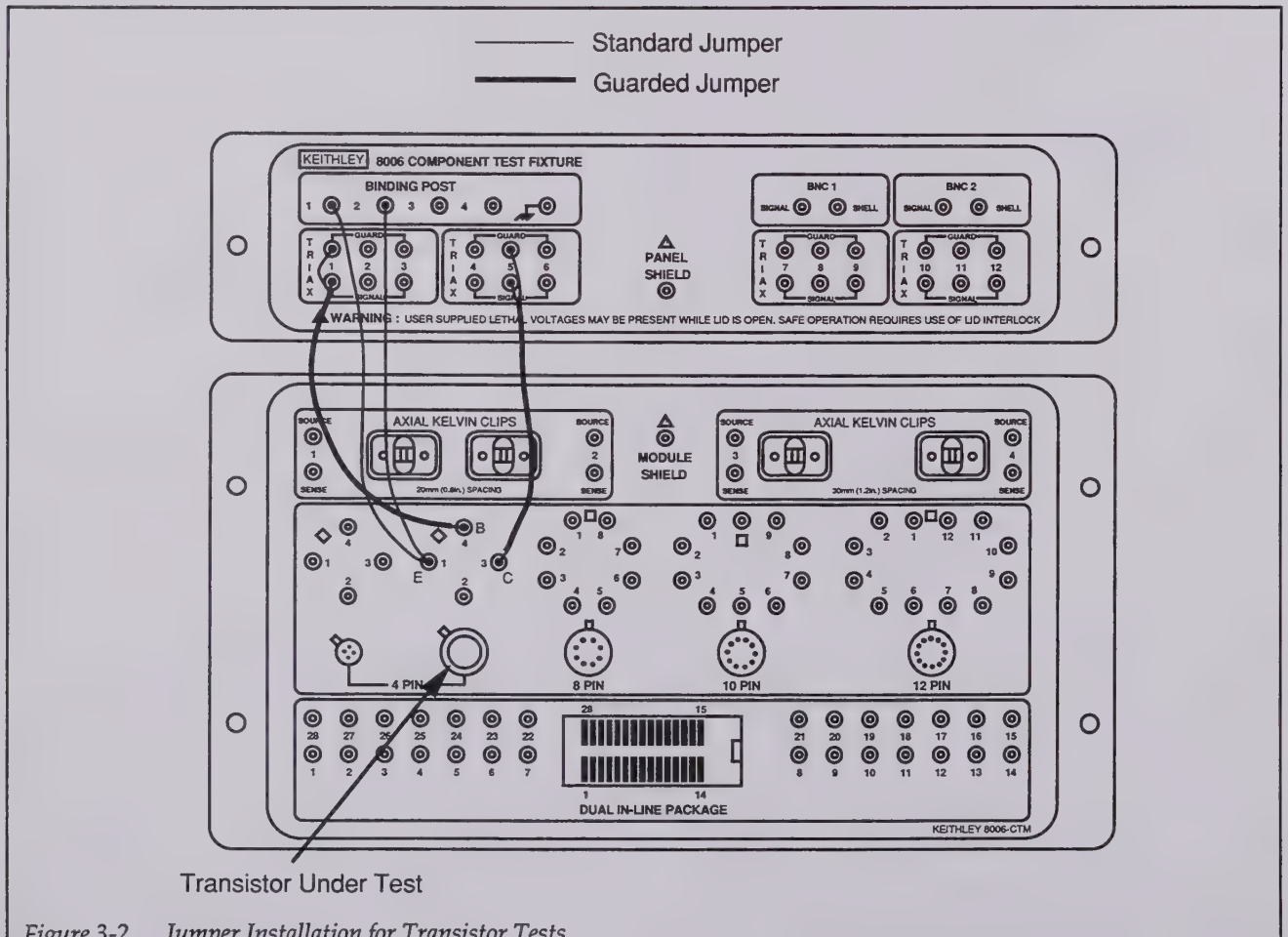


Figure 3-2. Jumper Installation for Transistor Tests

3.4 COMMON-EMITTER CHARACTERISTICS

Common-emitter characteristics are probably the most familiar type of curves generated for bipolar transistors. Test data used to generate these curves is obtained by sweeping the base current, I_B, across the desired range of values at specific increments. At each base current value, the collector-emitter voltage, V_{CE}, is swept across the desired range, again at specific increments. At each V_{CE} value, the collector current, I_C, is measured.

Once the data are collected, a plot of I_C vs. V_{CE} is generated for each value of I_B. The result is a family of curves that shows how I_C varies with V_{CE} at specific I_B values.

3.4.1 Test Configuration

Figure 3-3 shows the test configuration for the common-emitter characteristic tests. Unit #1 sweeps I_B across the desired range, and Unit #2 sweeps V_{CE} and measures I_C. Note that an NPN transistor is shown as part of the test configuration. A small-signal NPN transistor with an approximate current gain of 500 (such as a 2N5089) is recommended for use with the test program below. Other similar transistors such as a 2N3904 may also be used, but the program may require modification.

3.4.2 Measurement Considerations

A fixed delay period of 100msec, which is included in the program, may not be sufficient for testing some devices. Also, it may be necessary to change the programmed current values to optimize the tests for a particular device.

3.4.3 Program 4: Common-emitter Characteristics

Program 4 below can be used to run common-emitter characteristic tests on small-signal NPN transistors. In order to run the program, follow the steps below.

1. With the power off, connect both Model 236 Source Measure Units to the IEEE-488 interface of the computer.
2. Connect the test fixture to both units using appropriate cables (see Figure 3-1).
3. Turn on both Model 236 Source Measure Units, and allow the units to warm up for two hours for rated accuracy. Make sure the primary address of Unit #1 is set to 16 and that the primary address of Unit #2 is set to 17.
4. Turn on the computer, and boot up BASIC.
5. Enter the lines below into the computer.
6. Install a small-signal NPN silicon transistor such as a 2N5089 in the appropriate transistor socket of the test fixture. Be certain that the jumpers are properly installed, then close the test fixture lid.

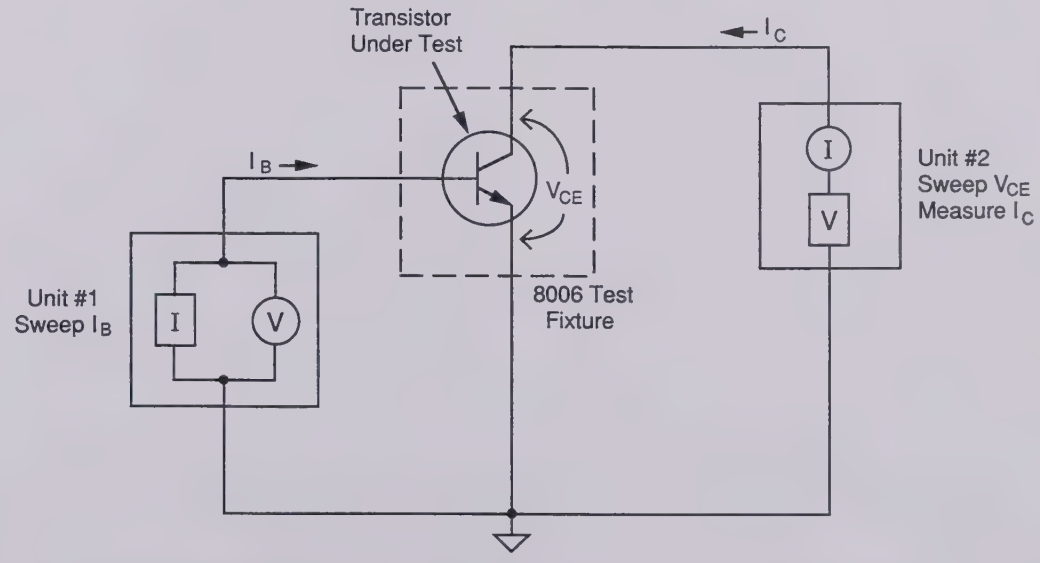


Figure 3-3. Test Configuration for Common-emitter Tests

7. RUN the program in the usual manner. The computer will program both units and run the common-emitter characteristic test on the device. The base current will be swept between 10μA and 50μA in 10μA increments, and the value of V_{CE} will be swept between 0V and 10V in 0.1V increments. A fixed delay of 100msec is also incorporated into the program.
8. Once the sweeps have been completed, you will be prompted to press CONT to generate a plot of the data. A simple I_C vs. V_{CE} plot will then be displayed on the computer CRT, with separate curves for each I_B value.
9. To return to BASIC from the graph, press CONT.

3.4.4 Typical Program 4 Results

Figure 3-4 shows typical results generated by example Program 4. A 2N5089 NPN silicon transistor was used to generate these test results.

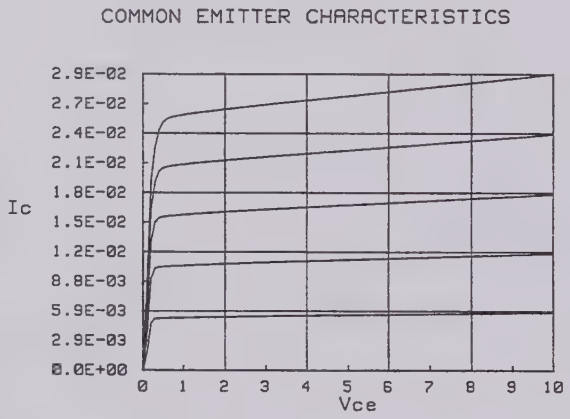


Figure 3-4. Example Plot from Test Program 4

3.4.5 Program 4 Description

For the following program description, refer to the program listing below and the flowchart shown in Figure 3-5.

Initially, the reading array is dimensioned (line 30) as a three-element array that will hold five sweeps of 101 points each, with two readings for each point. Next, both units are returned to default conditions by a DCL command (line 40), and Unit #1, which sweeps I_B, is set up as follows (lines 70-160):

- Source I, sweep mode

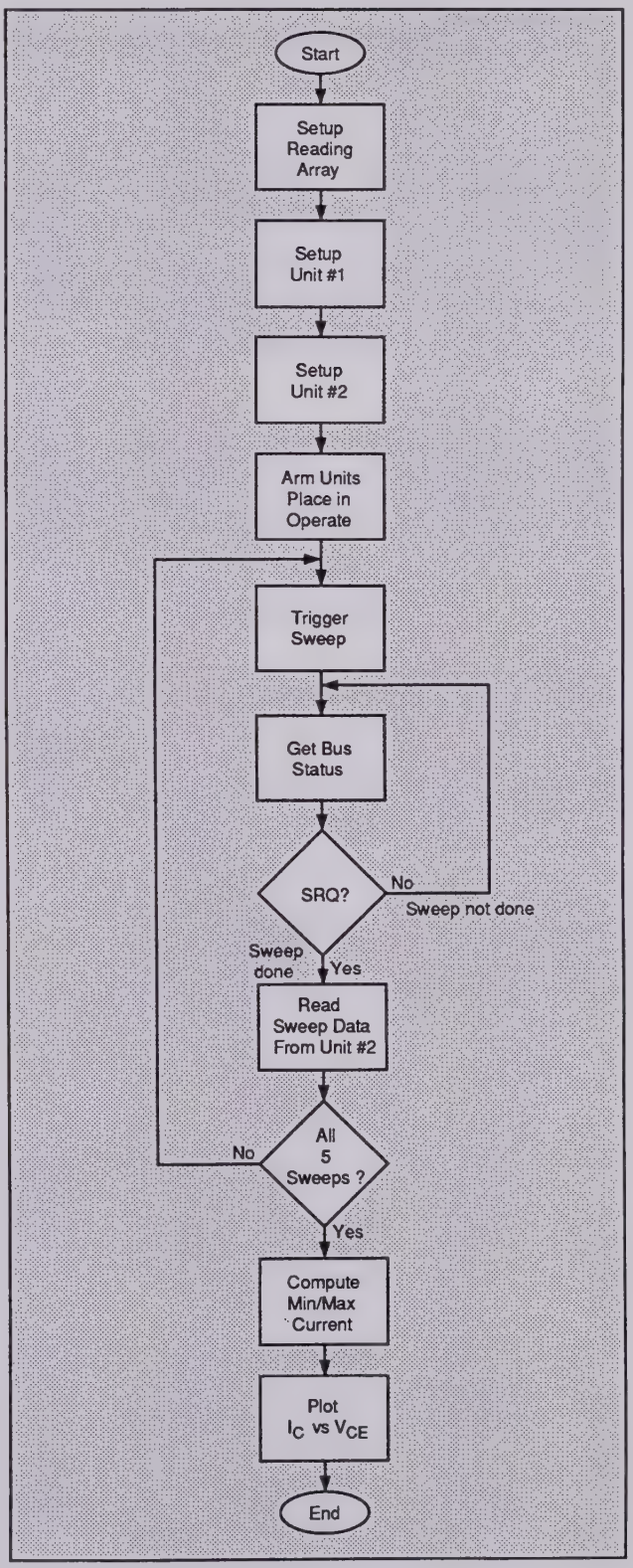


Figure 3-5. Program 4 Flowchart

- 1V compliance, 1.1V range
- Local sense
- Trigger on GET, one step per trigger, output trigger at end of delay
- Start I_B current: 10μA
- Stop I_B current: 50μA
- Step I_B current: 10μA
- Delay: 100msec
- Staircase sweep (limits determined by start, stop, and step current)

Following Unit #1 setup, Unit #2, which sweeps V_{CE} and measures I_C, is programmed as follows (lines 180-290):

- Source V, sweep mode
- Local sensing
- 100mA compliance, autorange measure
- Source measure data format with no prefix, sweep data
- SRQ on sweep done
- Trigger on external, one sweep per trigger
- Line cycle integration (to reduce noise)
- Suppress on (to null offsets)
- Start V_{CE} voltage: 0V
- Stop V_{CE} voltage: 10V
- Step V_{CE} voltage: 0.1V
- Staircase sweep (limits determined by start, stop, and step voltage)

Once the two units are ready to go, both triggers are armed and the units are placed into operate (lines 330 and 340). The main programming loop is then entered to generate the five I_B curve sweeps (line 350).

One of the key demonstrations of this test program is the subordinate-sweep configuration. To initiate each I_B curve sweep, Unit #1 is triggered over the bus by the IEEE GET command (line 370). This trigger causes Unit #1 to output the next programmed I_B current step. Following the programmed delay period, Unit #1 outputs a trigger pulse, which triggers Unit #2 to begin its sweep through all programmed V_{CE} values. At each V_{CE} value, Unit #2 measures I_C, and stores the data until the sweep is done.

In order to synchronize the program with each sweep, the program enters a loop to wait for Unit #2 to generate an SRQ (lines 380 and 390) when it has finished a sweep. Once each sweep has finished, Unit #2 is serial polled to clear the SRQ line (line 400), and the data are read into the reading array (line 420). Array element (I,J,1) stores source (V_{CE}) information, and array element (I,J,2) stores measured data (I_C) information. Once all the data pertaining to the present sweep are read, the program loops back to generate the next sweep at the subsequent I_B value (line 440).

In order to properly scale the plot, the maximum and minimum I_C values must be determined. This operation is performed in lines 500-570 of the program. Next, the data are plotted (lines 590-930). Note that the X axis of the graph is scaled by the Vstart and Vstop parameters (line 690), while the the Y axis is scaled by the maximum and minimum IC values. Plotting is performed on the reading data (lines 740-790); note that the plot array (PLOT (*)) statement cannot be used in this situation because of the three-element array used to store reading data.

3.4.6 Modifying the Program

As written, the sweep limits and increments are set to fixed values. For I_B, the start, stop, and step values are 10μA, 50μA, and 10μA respectively, and the start, stop, and step V_{CE} values are 0V, 10V, and 0.1V respectively. Again, you can modify the program as required, or include INPUT statements to allow operator input of these parameters. For sweep lengths other than 101 points, additional modifications such as array dimension and loop counter must also be made.

You can also speed up the sweep process by shortening the delay parameter (line 150) or changing the integration period (line 250). Doing so, however, may result in inaccurate readings or unacceptable noise levels.

```
10    REM COMMON EMITTER CHARACTERISTIC TEST PROGRAM REV. 1.3 (Program 4)
20    OPTION BASE 1                    ! First array subscript is 1
30    DIM Reading(5,101,2)             ! Dimension reading array (5 swps,101 pts)
40    CLEAR 7                          ! Clear both Units
50    OUTPUT KBD;CHR$(255);CHR$(75);   ! Clear screen
60    REM ***** Unit 1 setup (sweeps Ib). ****************************
70    REMOTE 716                       ! Put Unit 1 in remote
80    OUTPUT 716;"F1,1X"               ! Source I, sweep mode
90    OUTPUT 716;"L1,1X"               ! 1V compliance, 1.1V range
100   OUTPUT 716;"O0X"                 ! Local sense
110   OUTPUT 716;"T1,1,2,0X"           ! GET trigger cycle,out trig end of delay
115   OUTPUT 716;"B0,0,0X"             ! Program 0 bias value
120   Istart=1.0E-5                    ! Define 10uA start Ib current
130   Istop=5.0E-5                     ! Define 50uA stop Ib current
140   Istep=1.0E-5                     ! Define 10 uA step Ib current
150   Dly=100                          ! Define 100msec Unit delay
160   OUTPUT 716;"Q1,";Istart;",";Istop;",";Istep;",0,";Dly;"X" ! Pgm swp
170   REM ***** Unit 2 setup (sweeps Vce, measures Ic) ***************
180   REMOTE 717                       ! Put Unit 2 in remote
190   OUTPUT 717;"F0,1X"               ! Source V, sweep mode
200   OUTPUT 717;"O0X"                 ! Local sensing
210   OUTPUT 717;"L100E-3,0X"          ! 100mA compliance,autorange measure
220   OUTPUT 717;"G5,2,1X"             ! Source,measure,no prefix,sweep data
230   OUTPUT 717;"M2,X"                ! SRQ on sweep done
240   OUTPUT 717;"T3,0,0,0X"           ! Trigger on external,continuous
250   OUTPUT 717;"S2X"                 ! Line cycle integration
255   OUTPUT 717;"B0,0,0X"             ! Program 0 bias value
260   OUTPUT 717;"Z1X"                 ! Enable suppress
270   Vstart=0                         ! Define 0V start Vce
280   Vstop=10                         ! Define 10V stop Vce
290   Vstep=.1                         ! Define 0.1V step Vce
300   OUTPUT 717;"Q1,";Vstart;",";Vstop;",";Vstep;",0,";Dly;"X" ! Pgm swp
310   PRINT "Close lid, press CONT to begin test"
320   PAUSE
330   OUTPUT 716;"R1N1X"               ! Arm Unit 1 trigger,turn on output
340   OUTPUT 717;"R1N1X"               ! Arm Unit 2 trigger, turn on output
350   FOR I=1 TO 5                     ! Loop for five Ib curves
360   PRINT "Generating sweep";I
370   TRIGGER 716                      ! Trigger Unit 1
380   STATUS 7,7;Stat                  ! Get IEEE-488 bus status
390   IF NOT BIT(Stat,10) THEN 380     ! Wait for Unit 2 SRQ on sweep done
400   Stat=SPOLL(717)                  ! Serial poll Unit 2 to clear SRQ
410   FOR J=1 TO 101                   ! Loop for all 101 readings
420   ENTER 717;Reading(I,J,1),Reading(I,J,2)! Get Vce and Ic data from Unit 2
430   NEXT J                           ! Loop back for next reading
440   NEXT I                           ! Loop back for next Ib value
450   OUTPUT 716;"N0X"                 ! Turn off Unit 1 output
460   OUTPUT 717;"N0X"                 ! Turn off Unit 2 output
470   PRINT "Press CONT to display graph"
480   PRINT "Press CONT while in graph to return to BASIC"
490   PAUSE
500   Ymin=MAXREAL                     ! Find minimum and maximum Ic value
```

```
510   Ymax=-MAXREAL
520   FOR I=1 TO 5
530   FOR J=1 TO 101
540   IF Reading(I,J,2)<Ymin THEN Ymin=Reading(I,J,2)
550   IF Reading(I,J,2)>Ymax THEN Ymax=Reading(I,J,2)
560   NEXT J
570   NEXT I
580   OUTPUT KBD;CHR$(255);CHR$(75); ! Clear screen
590   GINIT                          ! Initialize graphics
600   PLOTTER IS CRT,"INTERNAL"      ! Define plot to CRT
610   GRAPHICS ON                    ! Turn on graphics
620   MOVE 20,95                     ! Title graph
630   LABEL "COMMON EMITTER CHARACTERISTICS"
640   MOVE 70,10                     ! Label X axis
650   LABEL "Vce"
660   MOVE 0,53                      ! Label Y axis
670   LABEL "Ic"
680   VIEWPORT 30,120,20,85          ! Define soft clip limits
690   WINDOW Vstart,Vstop,Ymin,Ymax  ! Scale graph
700   Y1=(Ymax-Ymin)/10              ! Compute Y axis increment
710   X1=(Vstop-Vstart)/10           ! Compute X axis increment
720   GRID 2*X1,2*Y1,Vstart,Ymin     ! Draw grid
730   AXES X1,Y1,Vstart,Ymin         ! Add some tick marks
740   FOR I=1 TO 5                   ! Loop for all five curves
750   FOR J=1 TO 101                 ! Loop for all 101 points per curve
760   PLOT Reading(I,J,1),Reading(I,J,2) ! Plot point
770   NEXT J                         ! Plot next point
780   PENUP                          ! Raise pen
790   NEXT I                         ! Plot next curve
800   CSIZE 4                        ! Define character size
810   LORG 6                         ! Center characters
820   CLIP OFF                       ! Turn off soft clip
830   FOR I=Vstart TO Vstop+.01*X1 STEP X1 ! Number X axis
840   MOVE I,Ymin-(Y1/4)
850   LABEL USING "#,K";I
860   NEXT I
870   FOR I=Ymin TO Ymax+.01*Y1 STEP Y1 ! Number Y axis
880   MOVE Vstart-(1.3*X1),I+(.3*Y1)
890   LABEL USING "#,MD.DE";I
900   NEXT I
910   PAUSE
920   OUTPUT KBD;CHR$(255);CHR$(75); ! Clear alpha screen
930   GRAPHICS OFF                   ! Clear graphics screen
940   END
```

3.5 GUMMEL PLOT

A Gummel plot is often used to determine current gain variations of a transistor. Data for a Gummel plot is obtained by sweeping the base-emitter voltage, V_{BE}, across the desired range of values at specific increments. At each V_{BE} value, both the base current, I_B, and collector current, I_C, are measured.

Once the data are taken, a plot of both I_B and I_C vs. V_{BE} is generated. Because of the large differences in magnitude between I_B and I_C, the Y axis is usually plotted logarithmically.

3.5.1 Test Configuration

Figure 3-6 shows the test configuration for Gummel plot tests. Unit #1 is used to sweep V_{BE} across the desired range, and it also measures I_B. Unit #2 sets V_{CE} to the desired fixed value, and it also measures I_C.

3.5.2 Measurement Considerations

As written, the range of V_{BE} test values is from 0.7V to 0V in –0.01V increments. It may be necessary, however, to change these limits for best results with your particular device. See paragraph 3.5.6 for information. Note that the plot is done in reverse order to optimize autoranging performance. Also, low currents will be measured so take the usual low-current precautions.

3.5.3 Program 5: Gummel Plot

Program 5 demonstrates the basic programming techniques for generating a Gummel plot. Follow the steps below to run this program.

1. With the power off, connect both Model 236 Source Measure Units to the IEEE-488 interface of the computer.
2. Connect the test fixture to both units using appropriate triax cables (see Figure 3-1).
3. Turn on both Model 236 Source Measure Units, and allow the units to warm up for two hours for rated accuracy. Make sure the primary address of Unit #1 is set to 16 and that the primary address of Unit #2 is set to 17.
4. Turn on the computer, and boot up BASIC.
5. Enter the lines below into the computer.
6. Install a small-signal NPN silicon transistor such as a 2N5089 in the appropriate transistor socket of the test fixture. Be certain that the jumpers are properly installed, then close the test fixture lid.
7. RUN the program in the usual manner. The computer will program both units and run the test on the device. The base-emitter voltage will be swept between 0.7V and 0V in –0.01V increments, and both I_B and I_C will be measured at each V_{BE} value. Note that a fixed collector-emitter voltage of 10V is used for the tests.

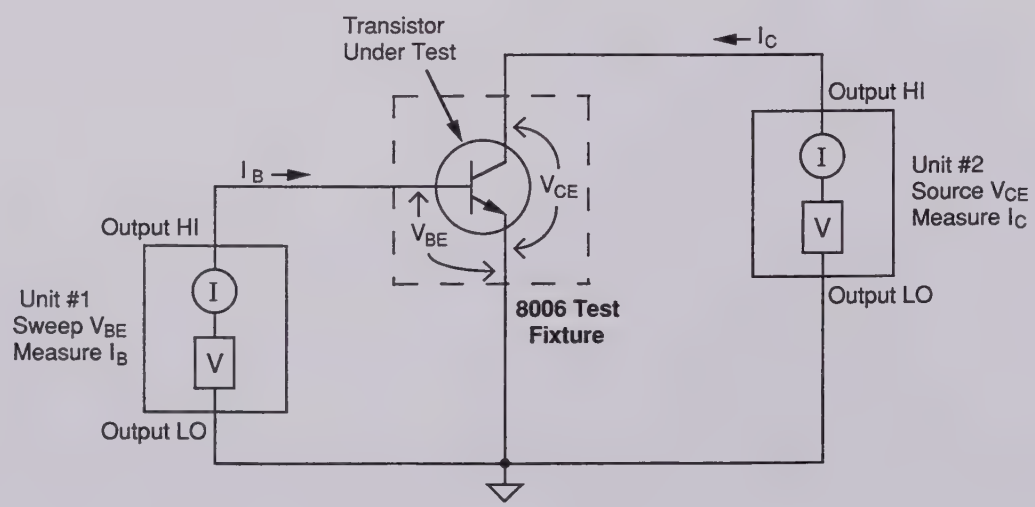


Figure 3-6. Gummel Plot Test Configuration

8. Once the sweep has been completed, you will be prompted to press CONT to generate a plot of the data. A simple I_B and I_C vs. V_{BE} plot will then be displayed on the computer CRT, with separate logarithmic curves for I_B and I_C.
9. To return to BASIC from the graph, press CONT.

3.5.4 Typical Program 5 Results

Figure 3-7 displays a typical Gummel plot as generated by example Program 5. Again, the transistor used for this example was a 2N5089 NPN silicon transistor.

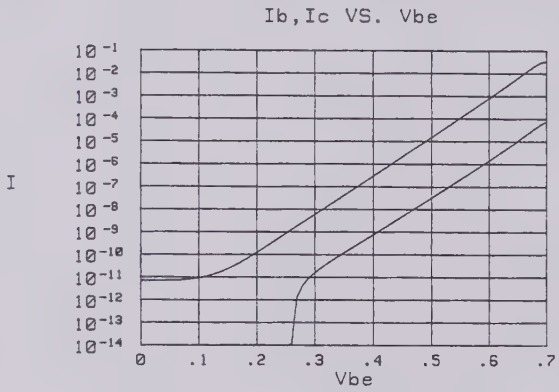


Figure 3-7. Example Plot from Test Program 5

3.5.5 Program 5 Description

Refer to the Program 5 listing below and the flowchart shown in Figure 3-8 for the following description.

Initially, the data array is set up (lines 20 and 30), and both Source Measure Units are returned to their default conditions (line 40). Next, Unit #1, which sweeps V_{BE} and measures I_B, is set up as follows (lines 70-180):

- Source V, sweep mode
- 1mA compliance, autorange measure
- Local sensing
- Source and measure data format, no prefix, output sweep data
- External trigger, trigger starts measurement phase, output trigger end of delay
- Line cycle integration
- Start V_{BE} voltage: 0.7V
- Stop V_{BE} voltage: 0V
- Step V_{BE} voltage: – 0.01V
- Staircase sweep (number of points determined by start, stop, and step voltages)
- 10msec delay

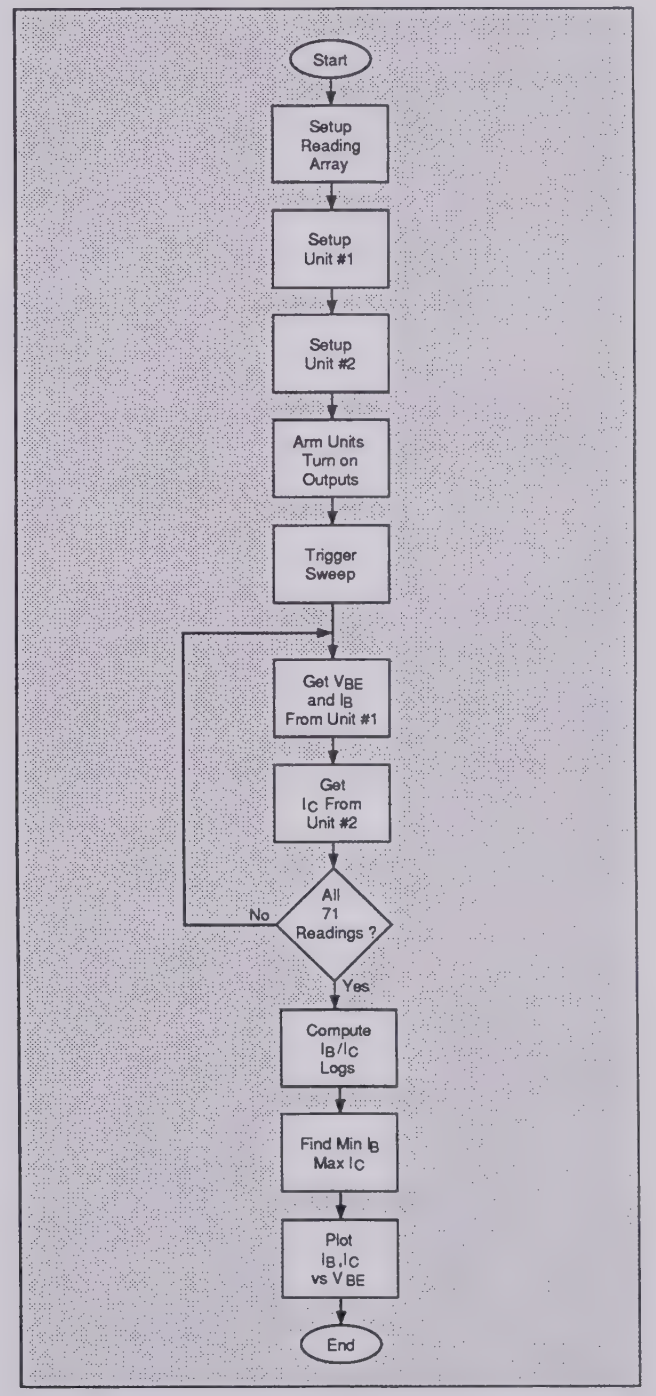


Figure 3-8. Program 5 Flowchart

Unit #2, which measures I_C, is programmed in the following manner (lines 200-290):

- Source V, sweep mode
- Local sensing
- 100mA compliance, autorange measure
- Measure data only, no prefix, sweep data
- Trigger on external, trigger starts source phase, output trigger on end of measurement
- Line cycle integration
- 10msec delay
- Constant sweep (number of points programmed to 71), V_{CE}=10V
- 10V bias voltage

Following unit setup, both unit triggers are armed, and the instruments are placed into the operate mode (lines 320 and 330).

Note that synchronized sweeps are used in this program, with Unit #1 triggering Unit #2 and vice versa. Since both Source Measure Units are programmed for the external trigger mode, the only way to trigger the test is to use the immediate trigger command, H0X (line 350). Once triggered, Unit #1 sets V_{BE} to the required value, and it then triggers Unit #2 at the end of the delay period. Unit #2 then sets V_{CE} and measures I_C at I_B. At the end of its measurement, Unit #2 triggers the next Unit #1 measurement, and the cycle repeats.

While sweep is being performed, a nested loop is entered to read the data from both units into the reading array (lines 360-390). Note that I_B and V_{BE} data from Unit #1 are placed into reading array elements (I,1) and I,2) respectively, while I_C data from Unit #2 is placed into reading array element (I,3).

Next, the the base 10 log of both I_B and I_C data is calculated (lines 440-490). At the same time, an arbitrary noise floor of 0.01pA is defined to eliminate offsets and noise in the final readings (lines 450-460). As pointed out earlier, these data are usually plotted logarithmically because of the wide differences between I_B and I_C. Finally, the maximum I_C and minimum I_B values are found in order to scale the Y axis of the graph (lines 510-560), and the closest even power of 10 for both maximum and minimum values are then set (lines 570 and 580). The results are then plotted in the usual manner (lines 600-1000).

3.5.6 Modifying the Program

If desired, you can modify the program for different sweeps by modifying the start, stop, and step currents to the required values (or add INPUT statements for run-time operator inputs). For sweep lengths other than 71, additional modifications such as array dimensioning and loop counters must also be included.

The fixed 10V V_{CE} value can also be modified, if required. Simply change the value declaration in the program, or add an INPUT statement for run-time operator input.

```
10    REM GUMMEL PLOT TEST PROGRAM REV. 1.3 (Program 5)
20    OPTION BASE 1                    ! First array subscript is 1
30    DIM Reading(71,3)                ! Dimension reading array (71 pts)
40    CLEAR 7                          ! Clear both Units
50    OUTPUT KBD;CHR$(255);CHR$(75);   ! Clear screen
60    REM ***** Unit 1 setup (sweeps Vbe, measures Ib) ************************
70    REMOTE 716                       ! Put Unit 1 in remote
80    OUTPUT 716;"F0,1X"               ! Source V, sweep mode
90    OUTPUT 716;"L1E-3,0X"            ! 1mA compliance,autorange measure
100   OUTPUT 716;"O0X"                 ! Local sense
110   OUTPUT 716;"G5,2,1X"             ! Source,measure,no prefix,sweep data
120   OUTPUT 716;"T3,4,2,0X"           ! Ext trigger,out trig end of delay
130   OUTPUT 716;"S2Z0X"               ! Line cycle integration,suppress off
135   OUTPUT 716;"B0,0,0X"             ! Program 0 bias value
140   Vstart=.7                        ! Define 0.7V start Vbe voltage
150   Vstop=0                          ! Define 0V stop Vbe voltage
160   Vstep=-.01                       ! Define -0.01V step Vbe voltage
170   Dly=10                           ! Define 10msec Unit delay
180   OUTPUT 716;"Q1,";Vstart;",";Vstop;",";Vstep;",0,";Dly;"X" ! Program sweep
190   REM ***** Unit 2 setup (sources Vce, measures Ic) ***************
200   REMOTE 717                       ! Put Unit 2 in remote
210   OUTPUT 717;"F0,1X"               ! Source V, sweep mode
220   OUTPUT 717;"O0X"                 ! Local sensing
230   OUTPUT 717;"L100E-3,0X"          ! 100mA compliance,autorange measure
240   OUTPUT 717;"G4,2,1X"             ! Measure,no prefix,sweep data
250   OUTPUT 717;"T3,1,4,0X"           ! External trigger, out trig end of meas
260   Vce=10                           ! Define 10V constant Vce
270   OUTPUT 717;"S2Z0X"               ! Line cycle integration,suppress off
280   OUTPUT 717;"B";Vce;",0,0X"       ! Set bias value to Vce
290   OUTPUT 717;"Q0,";Vce;",0,";Dly;",71X" ! Program constant sweep,71 points
300   PRINT "Close lid, press CONT to begin test"
310   PAUSE
320   OUTPUT 716;"R1N1X"               ! Arm Unit 1 trigger,turn on output
330   OUTPUT 717;"R1N1X"               ! Arm Unit 2 trigger,turn on output
340   PRINT "Generating sweep"
350   OUTPUT 716;"H0X"                 ! Trigger Unit 1 to start sweep
360   FOR I=1 TO 71                    ! Loop for all 71 readings
370   ENTER 716;Reading(I,1),Reading(I,2)! Get Vbe and Ib data from Unit 1
380   ENTER 717;Reading(I,3)           ! Get Ic data from Unit 2
390   NEXT I                           ! Loop back for next readings
400   OUTPUT 716;"N0X"                 ! Turn off Unit 1 output
410   OUTPUT 717;"N0X"                 ! Turn off Unit 2 output
420   PRINT "Press CONT to display graph"
430   PRINT "Press CONT while in graph to return to BASIC"
440   FOR I=1 TO 71                    ! Take LOG values of Ib and Ic
450   IF Reading(I,2)<1.E-14 THEN Reading(I,2)=1.E-14 ! Set Ib noise floor
460   IF Reading(I,3)<1.E-14 THEN Reading(I,3)=1.E-14 ! Set Ic noise floor
470   Reading(I,2)=LGT(Reading(I,2)) ! Take common log of Ib
480   Reading(I,3)=LGT(Reading(I,3)) ! Take common log of Ic
490   NEXT I                           ! Loop back for next data point
500   PAUSE
510   Ymin=MAXREAL                     ! Find minimum Ib and maximum Ic value
```

```
520   Ymax=-MAXREAL
530   FOR I=1 TO 71                    ! Loop for all 71 points
540   IF Reading(I,2)<Ymin THEN Ymin=Reading(I,2) ! Check Ymin against Ib
550   IF Reading(I,3)>Ymax THEN Ymax=Reading(I,3) ! Check Ymax against Ic
560   NEXT I                           ! Loop back for next point
570   Ymax=INT(Ymax)+1                 ! Scale Ymax to even power of 10
580   Ymin=INT(Ymin)                   ! Scale Ymin to even power of 10
590   OUTPUT KBD;CHR$(255);CHR$(75);   ! Clear screen
600   GINIT                            ! Initialize graphics
610   PLOTTER IS CRT,"INTERNAL"        ! Define plot to CRT
620   GRAPHICS ON                      ! Turn on graphics
630   MOVE 55,90                       ! Title graph
640   LABEL "Ib,Ic VS. Vbe"
650   MOVE 70,10                       ! Label X axis
660   LABEL "Vbe"
670   MOVE 0,53                        ! Label Y axis
680   LABEL "I"
690   VIEWPORT 30,120,20,85            ! Define soft clip limits
700   WINDOW Vstop,Vstart,Ymin,Ymax    ! Scale graph
710   Y1=1                             ! Define Y axis scaling increment
720   Y2=Ymin                          ! Define Y axis label value increment
730   Y3=ABS((Ymax-Ymin)/12)           ! Define Y axis label spacing increment
740   X1=(Vstart-Vstop)/7              ! Compute X axis increment
750   GRID X1,Y1,Vstop,Ymin            ! Draw grid
760   FOR I=71 TO 1 STEP -1            ! Loop for all 71 points
770   PLOT Reading(I,1),Reading(I,2) ! Plot Ib point
780   NEXT I                           ! Plot next Ib point
790   PENUP                            ! Raise pen
800   FOR I=71 TO 1 STEP -1            ! Loop for all 71 points
810   PLOT Reading(I,1),Reading(I,3) ! Plot Ic point
820   NEXT I                           ! Plot next Ic point
830   CSIZE 4                          ! Define character size
840   LORG 6                           ! Center characters
850   CLIP OFF                         ! Turn off soft clipping
860   FOR I=Vstop TO Vstart+.01*X1 STEP X1 ! Number X axis
870   MOVE I,Ymin-(Y3/4)
880   LABEL USING "#,K";I
890   NEXT I
900   FOR I=Ymin TO Ymax+.01*Y1 STEP Y1 ! Number Y axis
910   MOVE Vstop-(.95*X1),I+(.3*Y3)
920   CSIZE 4.5
930   LABEL "10"
940   MOVE Vstop-(.5*X1),I+(.35*Y3)
950   CSIZE 3
960   LABEL USING "#,K";I
970   NEXT I
980   PAUSE
990   OUTPUT KBD;CHR$(255);CHR$(75); ! Clear alpha screen.
1000  GRAPHICS OFF                     ! Clear graphics screen
1010  END
```

3.6 CURRENT GAIN

The following paragraphs discuss two methods for determining dc current gain, as well as ways to measure ac current gain.

3.6.1 Gain Calculations

The common-emitter dc current gain of a bipolar transistor is simply the ratio of the dc collector current to the dc base current of the device. The dc current gain is calculated as follows:

$$\beta = \frac{I_C}{I_B}$$

Where: β = current gain
I_C = dc collector current
I_B = dc base current

Often the differential or ac current gain is used instead of the dc value because it more closely approximates the performance of the transistor under small-signal ac conditions. In order to determine the differential current gain, two values of collector current (I_{C1} and I_{C2}) at two different base currents (I_{B1} and I_{B2}) are measured. The current gain is then calculated as follows:

$$\beta_{ac} = \frac{\Delta I_C}{\Delta I_B}$$

Where: β_{ac} = ac current gain
$\Delta I_C = I_{C2} - I_{C1}$
$\Delta I_B = I_{B2} - I_{B1}$

Test for both dc and ac current gain are generally done at one specific value of V_{CE}. Ac current gain tests should be performed with as small a ΔI_B as possible so that the device remains in the linear region of the curve.

3.6.2 Test Configuration for Search Method

Figure 3-9 shows the test configuration for the search method of dc current gain tests and ac gain tests. Unit #1 is used to supply I_{B1} and I_{B2}. Unit #2 sources V_{CE}, and it also measures the collector currents I_{C1} and I_{C2}.

3.6.3 Measurement Considerations

When entering the test base currents, take care not to enter values that will saturate the device. The approximate base current value can be determined by dividing the desired collector current value by the typical current gain for the transistor being tested.

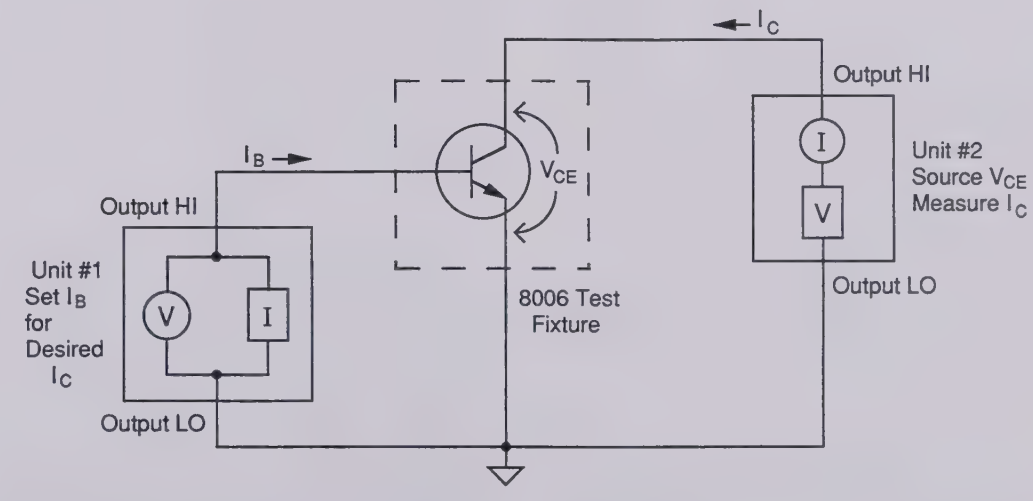


Figure 3-9. Test Configuration for Current Gain Tests Using Search Method

3.6.4 Program 6A: Dc Current Gain Using Search Method

Use Program 6A to perform dc current gain tests on bipolar transistors. Proceed as follows:

1. With the power off, connect both Model 236 Source Measure Units to the IEEE-488 bus of the computer.
2. Connect the test fixture to both units using appropriate triax cables (see Figure 3-1 for details on test connections).
3. Turn on both Source Measure Units, and allow them to warm up for at least two hours for rated accuracy. Be sure that the primary address of Unit #1 is set to 16, and that the primary address of Unit #2 is set to 17.
4. Turn on the computer, then boot up BASIC.
5. Enter the lines below into the computer
6. Install a small-signal NPN silicon transistor such as a 2N5089 in the desire test fixture socket. Install the required jumpers, then close the test fixture lid.
7. RUN the program, and follow the prompts on the screen. You will be prompted to enter the desired maximum and minimum base current values for the I_C search as well as the target collector current value, and the desired value of V_{CE}. When entering the base currents, keep the approximate current gain of the device in mind so as not to saturate the device. Also, enter a sufficient base current range to allow a successful search.
8. Once the parameters are entered, the units will be programmed accordingly, and the collector current of the device will be measured. The program will perform an iterative search to determine the closest match to the target I_C (within ±5%). The dc current gain of the device at specific I_B and I_C values will then be displayed on the computer CRT. If the search is unsuccessful, rerun the program with a more appropriate set of base current values.

3.6.5 Typical Program 6A Results

A typical current gain for a 2N5089 would be about 500. Note however, that the current gain of the device could be as low as 300 or as high as 800.

3.6.6 Program 6A Description

For the following description, refer to the flowchart shown in Figure 3-10 and the Program 6A listing shown below.

Initially, the iteration variables are defined (lines 20 and 30), and both units are returned to default conditions (line 40). Unit #1, which sources I_B, is set up as follows (lines 70-120):

- Source I, dc mode
- 1V compliance, 1.1V range
- Local sense
- GET trigger, continuous
- Dc current mode, value determined by user-input I_B value

The user is then prompted to enter the minimum and maximum I_B values, as well as the target I_C.

Following Unit #1 setup, Unit #2, which sources V_{CE} and measures I_C, is configured as follows (lines 180-250):

- Source V, dc mode
- Local sense
- 100mA compliance, autorange measure
- Source only data format, no prefix, dc data output
- Trigger on GET, continuous
- Dc voltage, value determined by user-input V_{CE} value
- Two-second delay

Once the operator signals to continue the program (lines 260 and 270), both Source Measure Unit triggers are armed and the units are placed into operate (lines 280 and 290). Next, the units are triggered (lines 310-320), and the iteration counter is incremented and tested against the programmed limit (lines 330 and 340). If the number of iterations has been exceeded, a message to that effect is displayed, and the program halts.

Assuming that the number of iterations has not been exceeded, Unit #1 is programmed with the base current value (line 390), and, after a two-second delay (line 410), the status byte is obtained from Unit #2 (line 420). Bit 7 in the status byte is then checked (lines 410-450) to see if it is set. If so, Unit #2 is over compliance, the operator is then notified, and the program is halted.

Assuming no error, the value of I_C is requested (line 470), and the value is checked against the target (lines 480-570) to see if it is within ±5%. If no match is found, a new I_B value is computed, and the program loops back to per-

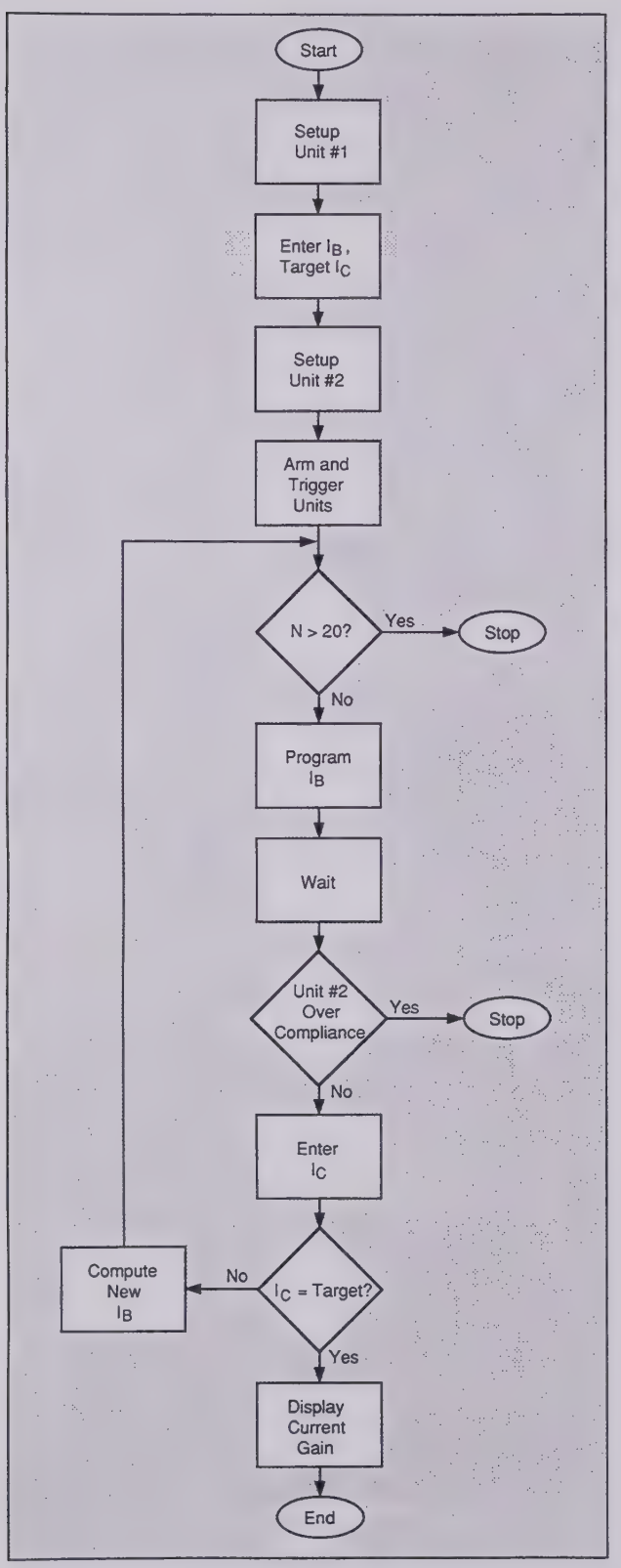


Figure 3-10. Program 6A Flowchart

form the test again at the new value. Finally, both units are placed into standby (lines 580 and 590), and the dc current gain is calculated and displayed (line 600).

3.6.7 Modifying Program 6A

For demonstration purposes, the I_C target match tolerance is set to ±5%. You can, of course, change this tolerance as required. Similarly, the iteration limit is set to 20. Again, this value can be adjusted for greater or fewer iterations as necessary. Note that it may be necessary to increase the number of iterations if the target range is reduced.

3.6.8 Configuration for Fast Current Gain Tests

Figure 3-11 shows the test configuration for an alternate method of current gain tests -- one that is much faster than the search method discussed previously. Unit #1 is used to supply V_{CE}, and it also measures I_B. Unit #2 sources the emitter current, I_E, rather than the collector current, I_C. Since we are sourcing emitter current instead of collector current, the current gain calculations must be modified as follows:

$$\beta = \frac{I_E - I_B}{I_B}$$

WARNING

When a Model 236/237 is programmed for remote sensing, hazardous voltage may be present on the SENSE and OUTPUT terminals when the unit is in operate regardless of the programmed voltage or current. To avoid a possible shock hazard, always turn off all power before connecting or disconnecting cables to the Source Measure Unit or the associated test fixture.

NOTE

Because of the connection convention used, I_E and V_{CE} must be programmed for opposite polarity than normal. With an NPN transistor, for example, both V_{CE} and I_E must be negative.

```
10    REM SEARCH METHOD DC CURRENT GAIN TEST PROGRAM REV. 1.3 (Program 6A)
20    Iterations=20                    ! Define number of iterations
30    N=0                              ! Iteration counter
40    CLEAR 7                          ! Clear both Units
50    OUTPUT KBD;CHR$(255);CHR$(75);   ! Clear screen
60    REM ***** Unit 1 setup (sources Ib) ****************************
70    REMOTE 716                       ! Put Unit 1 in remote
80    OUTPUT 716;"F1,0X"               ! Source I, DC mode
90    OUTPUT 716;"L1,1X"               ! 1V compliance, 1.1V range
100   OUTPUT 716;"O0Z0X"               ! Local sense,suppress off
110   OUTPUT 716;"T1,0,0,0X"           ! GET trigger,continuous
120   Dly=2000                         ! Define 2sec Unit delay
130   INPUT "Enter maximum base current",Ib1   ! Input max search Ib
140   INPUT "Enter minimum base current",Ib2   ! Input min search Ib
150   Ib=(Ib1-Ib2)/2+Ib2               ! Compute start Ib
160   INPUT "Enter target Ic value",Itarget   ! Input target Ic
170   REM ***** Unit 2 setup (sources Vce, measures Ic) ***************
180   REMOTE 717                       ! Put Unit 2 in remote
190   OUTPUT 717;"F0,0X"               ! Source V, DC mode
200   OUTPUT 717;"O0M128,0X"           ! Local sensing,SRQ.
210   OUTPUT 717;"L100E-3,0X"          ! 100mA compliance,autorange measure
220   OUTPUT 717;"G4,2,0Z0X"           ! Measure,no prefix,DC data,suppress off
230   OUTPUT 717;"T1,0,0,0X"           ! Trigger on GET,continuous
240   INPUT "Enter Vce",Vce            ! Input Vce
250   OUTPUT 717;"B";Vce;",0,";Dly;"X" ! Program DC,autorange,delay
260   PRINT "Close lid, press CONT to begin test"
270   PAUSE
280   OUTPUT 716;"R1N1X"               ! Arm Unit 1 trigger,turn on output
290   OUTPUT 717;"R1N1X"               ! Arm Unit 2 trigger,turn on output
300   PRINT "Measuring..."
310   TRIGGER 716                      ! Trigger Unit 1
320   TRIGGER 717                      ! Trigger Unit 2
330   N=N+1                            ! Increment iteration counter
340   IF N>Iterations THEN             ! Check for maximum iterations
350   BEEP
360   PRINT "More than";Iterations;"iterations"
370   STOP
380   END IF
390   OUTPUT 716;"B";Ib;",0,";Dly;"X" ! Program Ib
400   WAIT Dly/1000+1                  ! Wait for settling
410   Stat=SPOLL(717)                  ! Serial poll Unit 2
420   IF BIT(Stat,7) THEN              ! Check for over compliance
430   BEEP
440   PRINT "Unit 2 is over current compliance"
450   STOP
460   END IF
470   ENTER 717;Ic                     ! Get Ic reading from Unit 2
480   IF Ic>1.05*Itarget THEN          ! Check for Ic > target
490   Ib1=Ib
500   Ib=Ib-(Ib-Ib2)/10
```

```
510   GOTO 330
520   END IF
530   IF Ic<.95*Itarget THEN          ! Check for Ic < target
540   Ib2=Ib
550   Ib=Ib+(Ib1-Ib)/10
560   GOTO 330
570   END IF
580   OUTPUT 716;"N0X"                ! Turn off Unit 1 output
590   OUTPUT 717;"N0X"                ! Turn off Unit 2 output
600   PRINT "Current gain (@ Ib=";Ib;"Ic=";Ic;"):";Ic/Ib ! Display current gain
610   END
```

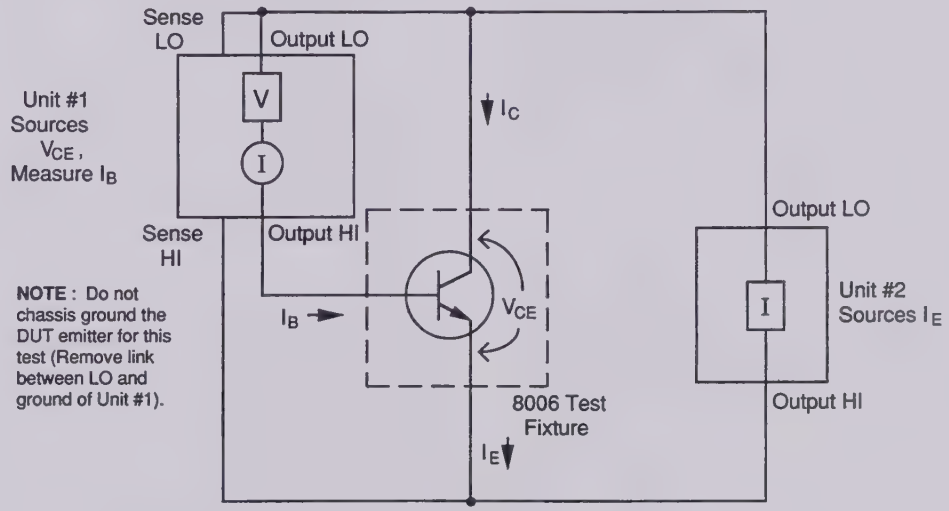


Figure 3-11. Test Configuration for Fast Current Gain Tests

3.6.9 Program 6B: Dc Current Gain Using Fast Method

Use Program 6B below to demonstrate the fast method of measuring current gain of bipolar transistors. Proceed as follows:

1. With the power off, connect both Model 236 Source Measure Units to the IEEE-488 bus of the computer.
2. Connect the test fixture to both units using appropriate triax cables (see Figure 3-1 and Figure 3-11 for details on instrument and test fixture connections). Note that OUTPUT HI of Unit #1 is connected to the base of the DUT, while SENSE HI of Unit #1 is connected to the emitter.
3. Turn on both Source Measure Units, and allow them to warm up for at least two hours for rated accuracy. Be sure that the primary address of Unit #1 is set to 16, and that the primary address of Unit #2 is set to 17.
4. Turn on the computer, then boot up BASIC.
5. Enter the lines below into the computer
6. Install a small-signal NPN silicon transistor such as a 2N3904 or 2N5089 in the desired test fixture socket. Install the required jumpers (use Figure 3-11 as a guide), then close the test fixture lid.
7. RUN the program as usual. The emitter current will be swept between 1mA and 10mA at 1mA increments. At each I_E value, the base current will be measured by Unit #1.
8. After the parameters are measured, the computer will request the test data from the units, and the emitter current and gain values will be displayed on the computer CRT. Note that the program reverses the polarity of the emitter currents in order to display true polarity.

3.6.10 Program 6B Description

For the following description, refer to the flowchart shown in Figure 3-12 and the Program 6B listing shown below.

Initially, both units are returned to default conditions (line 20). Unit #1, which sources V_{CE} and measures I_B, is set up as follows (lines 50-130):

- Source V, sweep mode
- 1mA compliance, autorange measure
- Remote sense
- External trigger, source phase start, output trigger end of measure
- Measure only data format, no prefix or suffix, sweep data
- 10msec delay
- Constant sweep mode, V_{CE} = –10V, constant sweep with 10 points.

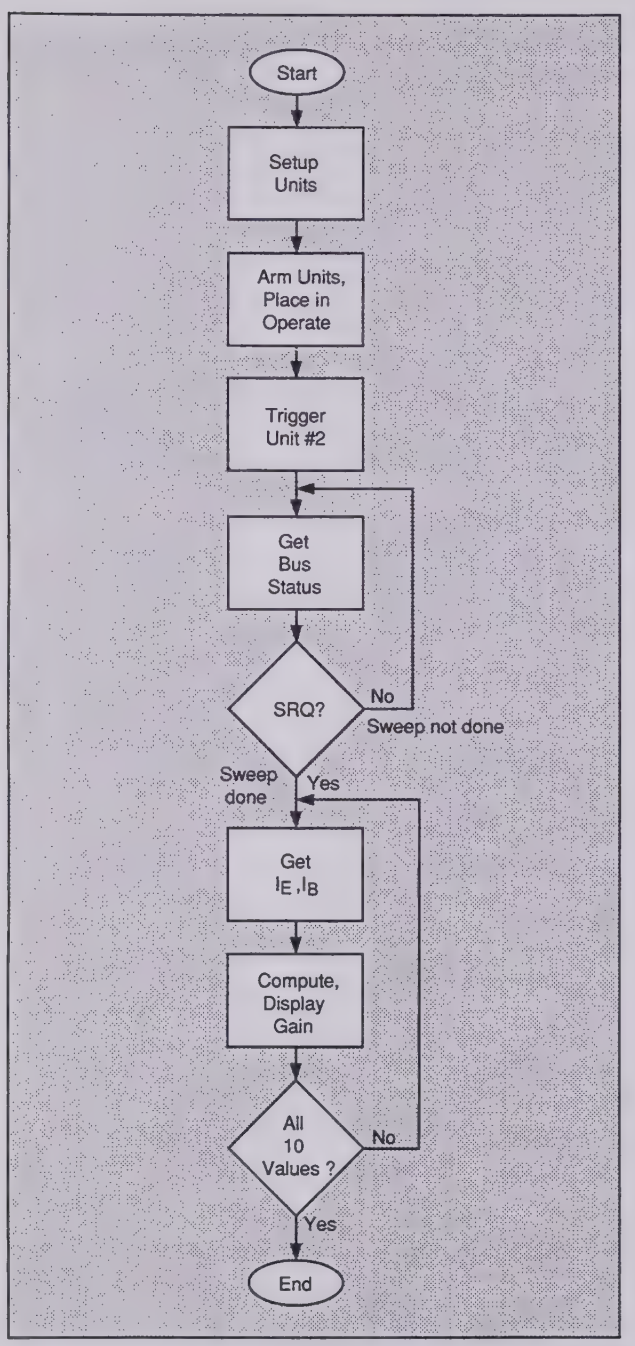


Figure 3-12. Program 6B Flowchart

Following Unit #1 setup, Unit #2, which sources I_E, is configured as follows (lines 150 -260):

- Source I, sweep mode
- Local sense
- 11V compliance, 11V range
- Source only data format, no prefix, sweep data output
- External trigger, start source phase, trigger out end of delay
- SRQ on sweep done
- Start current: –1mA
- Stop current: –10mA
- Step current: –1mA
- 10msec delay
- Staircase sweep mode

Once the operator signals to continue the program (lines 270 and 280), both Source Measure Unit triggers are armed and the units are placed into operate (lines 290 and 300). Next, Unit #2 is triggered to start the sweep (line 310), and the program enters a loop to wait for SRQ on sweep done (lines 330 and 340).

When the SRQ occurs, Unit #2 is serial polled in order to clear the SRQ (line 340), and both units are placed into standby (lines 350 and 360). The I_B and I_E values are requested (lines 410 and 420), and the current gain for each set of values is computed and displayed (line 430).

3.6.11 Modifying Program 6B

As written, the range of emitter current values is between –1mA and –10mA at –1mA increments. You can, of course, modify these values as required. Additional program modifications may be required if these parameters are changed. You could also add graphing capabilities to the program to plot current gain as a function of collector current by modifying the plotting routines from one of the other applications programs in this manual.

```
10    REM HIGH-SPEED  DC CURRENT GAIN TEST PROGRAM REV. 1.3 (Program 6B)
20    CLEAR 7                          ! Clear both Units
30    OUTPUT KBD;CHR$(255);CHR$(75);   ! Clear screen
40    REM ***** Unit 1 setup (sources Vce, measures Ib) **************
50    REMOTE 716                       ! Put Unit 1 in remote
60    OUTPUT 716;"F0,1X"               ! Source V, sweep mode
70    OUTPUT 716;"L1E-3,0X"            ! 1mA compliance, autorange measure
80    OUTPUT 716;"O1Z0X"               ! Remote sense,suppress off
90    OUTPUT 716;"T3,1,4,0X"           ! External trigger, out trig end of meas
100   OUTPUT 716;"G4,2,1X"             ! Measure only,no prefix,sweep data
101   OUTPUT 716;"B0,0,0X"             ! Program 0 bias value
110   Vce=-10                          ! Define -10V Vce
120   Dly=10                           ! Define 10msec delay
130   OUTPUT 716;"Q0,";Vce;",0,";Dly;",10X" ! Program fixed sweep, 10 points
140   REM ***** Unit 2 setup (sources Ie) ****************************
150   REMOTE 717                       ! Put Unit 2 in remote
160   OUTPUT 717;"F1,1X"               ! Source I, sweep mode
170   OUTPUT 717;"O0Z0X"               ! Local sensing,suppress off
180   OUTPUT 717;"L11,2X"              ! 11V compliance, 11V range
190   OUTPUT 717;"G1,2,1X"             ! Source,no prefix,sweep data
200   OUTPUT 717;"T3,1,2,0X"           ! External trigger, out trig end of delay
210   OUTPUT 717;"M2,X"                ! SRQ on sweep done
215   OUTPUT 717;"B0,0,0X"             ! Program 0 bias value
220   Istart=-1.E-3                    ! Define -1mA start Ie current
230   Istop=-1.0E-2                    ! Define -10mA stop Ie current
240   Istep=-1.E-3                     ! Define -1mA step Ie current
250   Dly=10                           ! Define 10msec delay
260   OUTPUT 717;"Q1,";Istart;",";Istop;",";Istep;",0,";Dly;"X"
270   PRINT "Close lid, press CONT to begin test"
280   PAUSE
290   OUTPUT 716;"R1N1X"               ! Arm Unit 1 trigger,turn on output
300   OUTPUT 717;"R1N1X"               ! Arm Unit 2 trigger,turn on output
310   OUTPUT 717;"H0X"                 ! Trigger Unit 2 to start sweep
320   STATUS 7,7;Stat                  ! Get bus status
330   IF NOT BIT(Stat,10) THEN 320     ! Wait for SRQ
340   Stat=SPOLL(717)                  ! Serial poll Unit 2 to clear SRQ
350   OUTPUT 716;"N0O0X"               ! Turn off Unit 1 output,local sense
360   OUTPUT 717;"N0X"                 ! Turn off Unit 2 output
370   PRINT "Ie","GAIN"
380   PRINT "-------------------------"
390   PRINT
400   FOR I=1 TO 10
410   ENTER 716;Ib                     ! Get base current from Unit 1
420   ENTER 717;Ie                     ! Get emitter current from Unit 2
430   PRINT -Ie,(-Ie-Ib)/Ib            ! Compute/display gain
440   NEXT I
450   END
```

3.6.12 Program 7: Ac Current Gain

NOTE
For the sake of simplicity, this program does not include the iterative search algorithm included in Program 6A. To test at a specific I_C value, first use Program 6A to determine the base current at that target value, and enter I_B values slightly above and below when prompted to do so in Program 7.

1. With the power off, connect both Model 236 Source Measure Units to the IEEE-488 bus of the computer.
2. Connect the test fixture to both units using appropriate triax cables (see Figure 3-1 and Figure 3-9 for details on test connections).
3. Turn on both Source Measure Units, and allow them to warm up for at least two hours for rated accuracy. Be sure that the primary address of Unit #1 is set to 16, and that the primary address of Unit #2 is set to 17.
4. Turn on the computer, then boot up BASIC.
5. Enter the lines below into the computer
6. Install a small-signal NPN silicon transistor in the desired test fixture socket. Install the required jumpers, then close the test fixture lid.
7. RUN the program, and follow the prompts on the screen. You will be prompted to enter two base current values and then the desired value of V_{CE}. When entering the base current, keep the the two values as close together as possible so that the device remains in its linear operating region. A change in I_B of about 20% from one value to another would be a good starting point.
8. Once the parameters are entered, the units will be programmed accordingly, and both the collector currents of the device (one at each base current value) will be measured. The ac current gain of the device will then be displayed on the computer CRT.

3.6.13 Typical Program 7 Results

The differential current gain obtained for a given sample of a 2N5089 NPN transistor would typically be about the same as the dc current gain-about 500. Again, values could range from a low of 300--to a high of 800 or so.

3.6.14 Program 7 Description

For the following description, refer to the flowchart shown in Figure 3-13 and the Program 7 listing shown below.

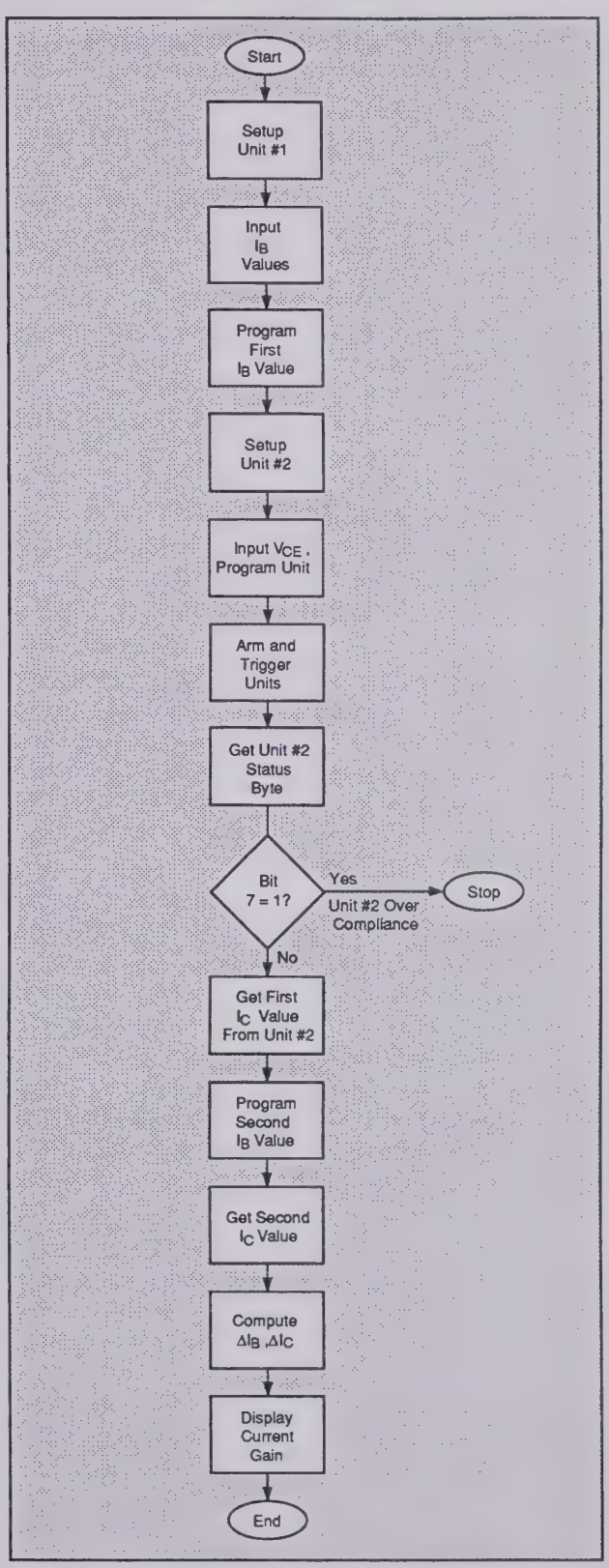


Figure 3-13. Program 7 Flowchart

After both units are returned to default conditions (line 20), Unit #1 is set up as follows (lines 50-120):

- Source I, dc mode
- 1V compliance, 1.1V range
- Local sense
- GET trigger, continuous
- Dc current mode, I_B values determined by user input

Following Unit #1 setup, Unit #2 is configured as follows (lines 140-200):

- Source V, dc mode
- Local sense
- 100mA compliance
- Source only data format, no prefix, dc data output
- Trigger on GET, continuous
- Two-second source-measure delay
- Dc voltage, value determined by user-input V_{CE} value

Once the operator signals to continue the program (lines 230 and 240), both Source Measure Unit triggers are armed and the units are placed into operate (lines 250 and 260). Next, the units are triggered (lines 280 and 290), and the status byte is obtained from Unit #2 (line 310). Bit 7 in the status byte is then checked (lines 320-350) to see if it is set. If so, Unit #2 is over compliance, the operator is then notified, and the program is halted.

Assuming no error, the value of I_{C1} is requested (line 370), and Unit #1 is programmed with the second base current value, I_{B2} (line 380). The second collector current, I_{C2}, is then requested from the unit (line 400), and ΔI_B and ΔI_C are then computed (lines 410 and 420). Both units are placed into standby (lines 430 and 440), and, finally, the differential current gain is calculated and displayed (line 450).

3.6.15 Modifying Program 7

As with the dc current gain, ac current gain is often tested at specific values of I_C. Again, a search algorithm similar to the one in Program 6A could be added to the program. Such an algorithm would allow you to enter the desired collector current values, and it would then perform an iterative search to automatically determine the two correct base current values that would result in the desired collector currents.

```
10    REM DIFFERENTIAL CURRENT GAIN TEST PROGRAM REV. 1.3 (Program 7)
20    CLEAR 7                          ! Clear both Units
30    OUTPUT KBD;CHR$(255);CHR$(75);   ! Clear screen
40    REM ***** Unit 1 setup (sources Ib) ****************************
50    REMOTE 716                       ! Put Unit 1 in remote
60    OUTPUT 716;"F1,0X"               ! Source I, DC mode
70    OUTPUT 716;"L1,1X"               ! 1V compliance, 1.1V range
80    OUTPUT 716;"O0X"                 ! Local sense
90    OUTPUT 716;"T1,0,0,0X"           ! GET trigger,continuous
100   INPUT "Enter first base current",Ib1 ! Input first base current
110   INPUT "Enter second base current",Ib2! Input second base current
120   OUTPUT 716;"B";Ib1;",0,0X"       ! Program DC value, autorange, delay
130   REM ***** Unit 2 setup (sources Vce, measures Ic) ***************
140   REMOTE 717                       ! Put Unit 2 in remote
150   OUTPUT 717;"F0,0X"               ! Source V, DC mode
160   OUTPUT 717;"O0M128,0Z0X"         ! Local sensing,SRQ,suppress off
170   OUTPUT 717;"L100E-3,0X"          ! 100mA compliance,autorange measure
180   OUTPUT 717;"G4,2,0X"             ! Measure,no prefix,DC data
190   OUTPUT 717;"T1,0,0,0X"           ! Trigger on GET,continuous
200   Dly=2000                         ! Define 2sec Unit 2 delay
210   INPUT "Enter Vce",Vce            ! Input Vce
220   OUTPUT 717;"B";Vce;",0,";Dly;"X" ! Program DC,autorange,delay
230   PRINT "Close lid, press CONT to begin test"
240   PAUSE
250   OUTPUT 716;"R1N1X"               ! Arm Unit 1 trigger,turn on output
260   OUTPUT 717;"R1N1X"               ! Arm Unit 2 trigger,turn on output
270   PRINT "Measuring..."
280   TRIGGER 716                      ! Trigger Unit 1
290   TRIGGER 717                      ! Trigger Unit 2
300   WAIT Dly/1000+1                  ! Settling time
310   Stat=SPOLL(717)                  ! Serial poll Unit 2
320   IF BIT(Stat,7) THEN              ! Check for over compliance
330   BEEP
340   PRINT "Unit is over current compliance"
350   STOP
360   END IF
370   ENTER 717;Ic1                    ! Get first Ic reading from Unit 2
380   OUTPUT 716;"B";Ib2;",0,";Dly;"X" ! Program Unit 1 for second Ib value
390   WAIT 2                           ! Wait two second for settling
400   ENTER 717;Ic2                    ! Get second Ic reading from Unit 2
410   Delta_ib=ABS(Ib2-Ib1)            ! Compute delta Ib
420   Delta_ic=ABS(Ic2-Ic1)            ! Compute delta Ic
430   OUTPUT 716;"N0X"                 ! Turn off Unit 1 output
440   OUTPUT 717;"N0X"                 ! Turn off Unit 2 output
450   PRINT "Differential current gain=";Delta_ic/Delta_ib ! Display gain
460   END
```

3.7 TRANSISTOR LEAKAGE CURRENT

Leakage currents, such as I_{CBO} (collector-base, emitter open) and I_{CEO} (collector-emitter, base open) can be tested using a single Source Measure Unit. The following paragraphs discuss I_{CEO} tests and also include an example program for making such tests.

3.7.1 Test Configuration

Figure 3-14 shows the basic test configuration for performing I_{CEO} tests. Note that only one Source Measure Unit is required to make such tests. The Source Measure Unit sources the collector-emitter voltage, V_{CEO}, and the instrument also measures I_{CEO}. Often, V_{CEO} is swept across the desired range of values, and the resulting I_{CEO} values are plotted against V_{CEO}, as is the case with the example program included in this section.

The base of the transistor should be left open. The same general circuit configuration can be used to measure I_{CBO}; connect the Source Measure Unit between the collector and base, and leave the emitter open instead.

Breakdown tests can also be performed using the same I_{CEO} circuit setup. In this case, the Source Measure Unit is used to source I and measured the breakdown voltage, V, in order to better control device power at breakdown.

3.7.2 Program 8: I_{CEO} Test

Use Program 8 below to run I_{CEO} tests on bipolar transistors. Follow the steps below to run the program.

1. With the power off, connect the Model 236 Source Measure Unit to the IEEE-488 interface of the computer.
2. Connect the test fixture to the Source Measure Unit using appropriate triax cables (see Figure 2-1 for details on single-unit connections).
3. Turn on the Model 236 Source Measure Unit, and allow the unit to warm up for two hours for rated accuracy. Make sure the primary address of the unit is set to 16.
4. Turn on the computer, and boot up BASIC.
5. Enter the lines below into the computer.
6. Install a small-signal NPN silicon transistor such as a 2N3904 in the appropriate transistor socket of the test fixture. Be certain that the jumpers are properly installed to collector and emitter only (the base terminal should be left open), then close the test fixture lid.
7. RUN the program in the usual manner. The computer will program the unit and run the test on the device. V_{CEO} will be swept between 0V and 10V in 0.1V increments, and I_{CEO} will be measured at each V_{CEO} value. A fixed delay of 100msec is also incorporated into the program. Because of the low current levels involved, line-cycle integration is used to reduce noise levels.
8. Once the sweep has been completed, you will be prompted to press CONT to generate a plot of the

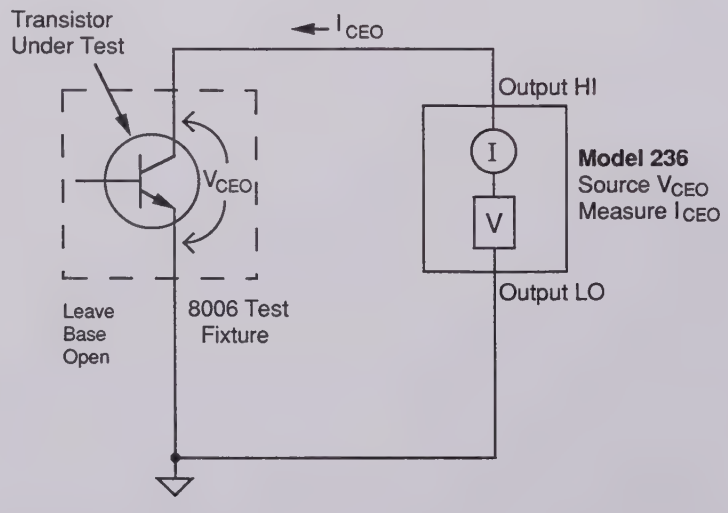


Figure 3-14. Configuration for I_{CEO} Tests

data. A simple I_{CEO} vs. V_{CEO} plot will then be displayed on the computer CRT.

9. To return to BASIC from the graph, press CONT.

3.7.3 Typical Program 8 Results

Figure 3-15 shows an example I_{CEO} vs. V_{CEO} plot generated by Program 8. The device used for this example was a 2N3904 NPN transistor.

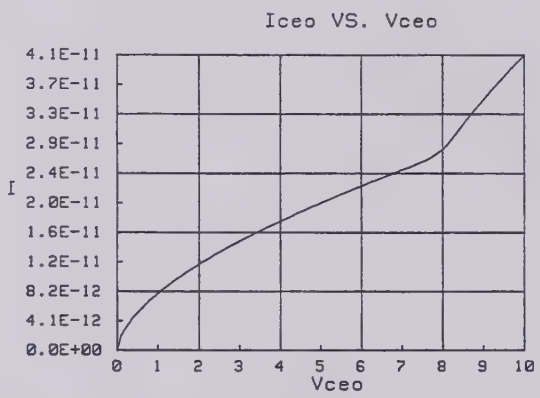


Figure 3-15. Example Program 8 Plot

3.7.4 Program 8 Description

Refer to Figure 3-16 and the listing below for the following description.

At the start of the program, the array is set up to handle 101 data points with two values for each point (lines 20 and 30). After being cleared (line 40), the Source Measure Unit, which sweeps V_{CEO} and measures I_{CEO}, is set up as follows:

- Source V, sweep mode
- Local sense, trigger on GET, continuous
- 10mA compliance, autorange measure
- Source and measure data format, no prefix, sweep data
- SRQ on sweep done
- Line cycle integration
- Suppress on (to null offset current)
- Start V_{CEO} voltage: 0V
- Stop V_{CEO} voltage: 10V
- Step V_{CEO} voltage: 0.1V
- Staircase sweep mode

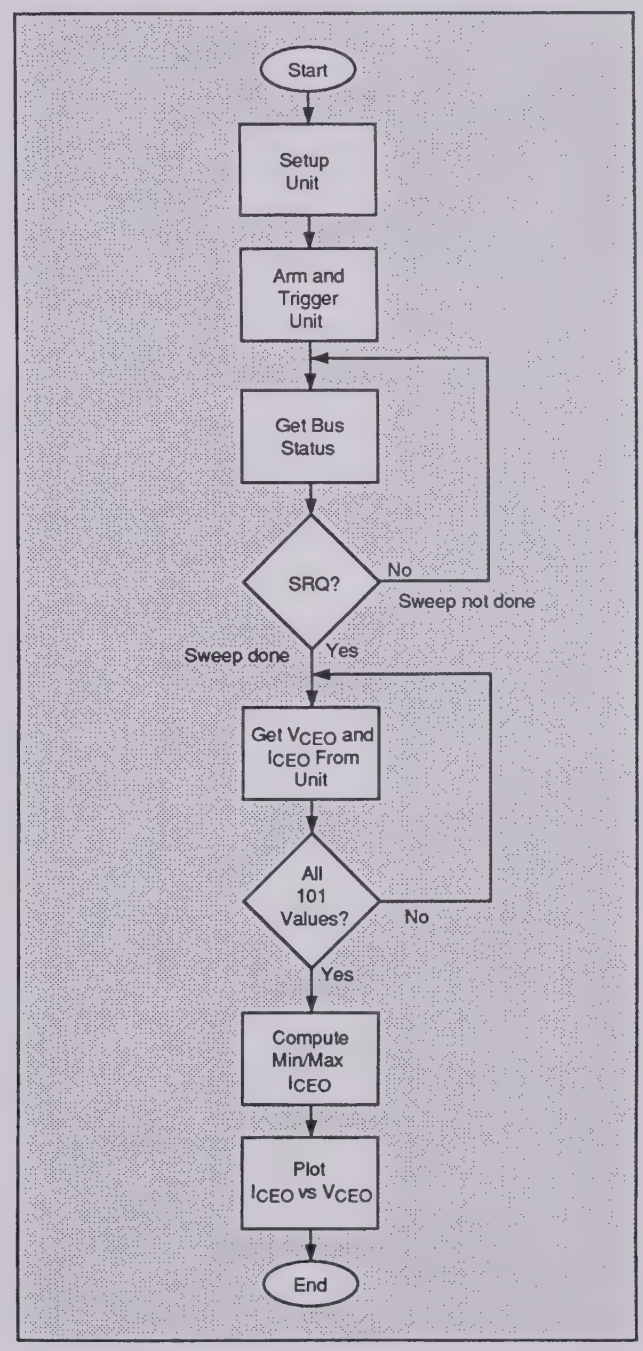


Figure 3-16. Program 8 Flowchart

After the start signal from the operator (lines 190 and 200), the trigger is armed (line 210) and the unit is placed into operate (line 220). Next, the unit is triggered to begin the sweep (line 230), and the program enters a loop waiting for the unit to generate an SRQ on sweep done (lines 250-260).

When the sweep is done, the unit generates the SRQ, the program falls through the loop, and it then serial polls the unit to clear the SRQ (line 270). The unit is placed in standby (line 280), and the program enters a loop to request sweep data from the instrument (lines 290-310). Note that V_{CEO} values are placed into elements (I,1), and I_{CEO} values are stored in elements (I,2) of the reading array.

The maximum and minimum I_{CEO} values are then determined (lines 340-370, and the data is then graphed on the computer CRT (lines 420-670). A simple plot, scaled to maximum and minimum I_{CEO} and V_{CEO} values is generated on the computer CRT.

3.7.5 Modifying Program 8

For different sweep values, simply modify the Vstart, Vstop, and Vstep values and source range parameter as appropriate. As an alternative, you can add INPUT statements with appropriate error checking to allow operator input of these parameters.

In order to speed up the test procedure, you may wish to use a faster integration period. Simply change the command string in line 120 as appropriate. Note, however, that changing this parameter may result in unacceptable reading noise.

```
10    REM  BIPOLAR TRANSISTOR LEAKAGE TEST PROGRAM REV. 1.3 (Program 8)
20    OPTION BASE 1                          ! First array subscript is 1
30    DIM Reading(101,2)                     ! Dimension reading array (101 pts.)
40    CLEAR 7                                ! Clear 236
50    REMOTE 716                             ! Put 236 in remote
60    OUTPUT KBD;CHR$(255);CHR$(75);         ! Clear screen
70    OUTPUT 716;"F0,1X"                     ! Source V, sweep mode
80    OUTPUT 716;"O0T1,0,0,0X"               ! Local sense, trigger on GET
90    OUTPUT 716;"L10E-3,0X"                 ! 10mA compliance, autorange measure
100   OUTPUT 716;"G5,2,1X"                   ! Source,measure,no prefix,sweep data
110   OUTPUT 716;"M2,X"                      ! SRQ on sweep done
120   OUTPUT 716;"S2X"                       ! Line cycle integration
125   OUTPUT 716;"B0,0,0X"                   ! Program 0 bias value
130   OUTPUT 716;"Z1X"                       ! Enable suppress
140   Vstart=0                               ! Define 0V start voltage
150   Vstop=10                               ! Define 10V stop voltage
160   Vstep=.1                               ! Define 0.1V step voltage
170   Dly=100                                ! Define 100msec delay value
180   OUTPUT 716;"Q1,";Vstart;",";Vstop;",";Vstep;",0,";Dly;"X" !  Program sweep
190   PRINT "Close lid, press CONT to begin"
200   PAUSE                                  ! Wait to continue
210   OUTPUT 716;"R1X"                       ! Arm trigger
220   OUTPUT 716;"N1X"                       ! Turn on 236 output
230   TRIGGER 716                            ! Trigger 236
240   PRINT "Waiting for sweep to end"
250   STATUS 7,7;Stat                        ! Get IEEE-488 bus status
260   IF NOT BIT(Stat,10) THEN 250           ! Wait for SRQ on sweep done
270   Stat=SPOLL(716)                        ! Serial poll 236 to clear SRQ
280   OUTPUT 716;"N0X"                       ! Turn off 236 output
290   FOR I=1 TO 101                         ! Loop for all readings
300   ENTER 716;Reading(I,1),Reading(I,2)! Get Vceo and Iceo values from Unit
310   NEXT I                                 ! Loop back for next reading
320   Ymin=MAXREAL                           ! Find minimum and maximum Iceo
330   Ymax=-MAXREAL
340   FOR I=1 TO 101
350   IF Reading(I,2)<Ymin THEN Ymin=Reading(I,2)
360   IF Reading(I,2)>Ymax THEN Ymax=Reading(I,2)
370   NEXT I
380   PRINT "Press CONT to display graph"
390   PRINT "Press CONT while in graph to return to BASIC"
400   PAUSE
410   OUTPUT KBD;CHR$(255);CHR$(75);         ! Clear screen
420   GINIT                                  ! Initialize graphics
430   PLOTTER IS CRT,"INTERNAL"              ! Define plot to CRT
440   GRAPHICS ON                            ! Turn on graphics
450   MOVE 50,90                             ! Title graph
460   LABEL "Iceo VS. Vceo"
470   MOVE 70,10                             ! Label X axis
480   LABEL "Vceo"
490   MOVE 5,53                              ! Label Y axis
500   LABEL "I"
```

```
510   VIEWPORT 30,120,20,85                ! Define soft clip limits
520   WINDOW Vstart,Vstop,Ymin,Ymax        ! Scale graph
530   Y1=(Ymax-Ymin)/10                    ! Compute Y axis increment
540   X1=(Vstop-Vstart)/10                 ! Compute X axis increment
550   GRID 2*X1,2*Y1,Vstart,Ymin           ! Draw grid
560   AXES X1,Y1,Vstart,Ymin               ! Add some tick marks
570   PLOT Reading(*)                      ! Plot data
580   CSIZE 4                              ! Define character size
590   LORG 6                               ! Center characters
600   CLIP OFF                             ! Turn off soft clipping
610   FOR I=Vstart TO Vstop+.01*X1 STEP X1 ! Number X axis
620   MOVE I,Ymin-(Y1/4)
630   LABEL USING "#,K";I
640   NEXT I
650   FOR I=Ymin TO Ymax+.01*Y1 STEP Y1    ! Number Y axis
660   MOVE Vstart-(1.3*X1),I+(.3*Y1)
670   LABEL USING "#,MD.DE";I
680   NEXT I
690   PAUSE
700   OUTPUT KBD;CHR$(255);CHR$(75);       ! Clear alpha screen
710   GRAPHICS OFF                         ! Clear graphics screen
720   END
```

SECTION 4
FET Tests

4.1 INTRODUCTION

FET tests discussed in this section include: tests to generate common-source characteristic curves, and transconductance tests. Example programs for each of these applications are also included.

4.2 INSTRUMENT CONNECTIONS

Figure 4-1 shows the instrument connections for the FET tests outlined in this section. Note that these connections are essentially identical to the connections used for the bipolar transistor tests discussed in Section 3. Two Model 236/237 Source Measure Units are required for the tests, and, once again, the Model 8006 test fixture is recommended for connections to the FET under test.

A Model 7078-TRX-3 triax cables are recommended to make instrument-to-test fixture connections. In addition, the safety interlock connecting cable must be connected as shown.

WARNING

Lethal voltages may be exposed when the test fixture lid is open. To avoid a possible shock hazard, the safety interlock circuit must be connected as shown in Figure 4-1 before use. Connect the fixture ⏚ screw to safety earth ground using #18 AWG minimum wire before use. Turn off all power be-

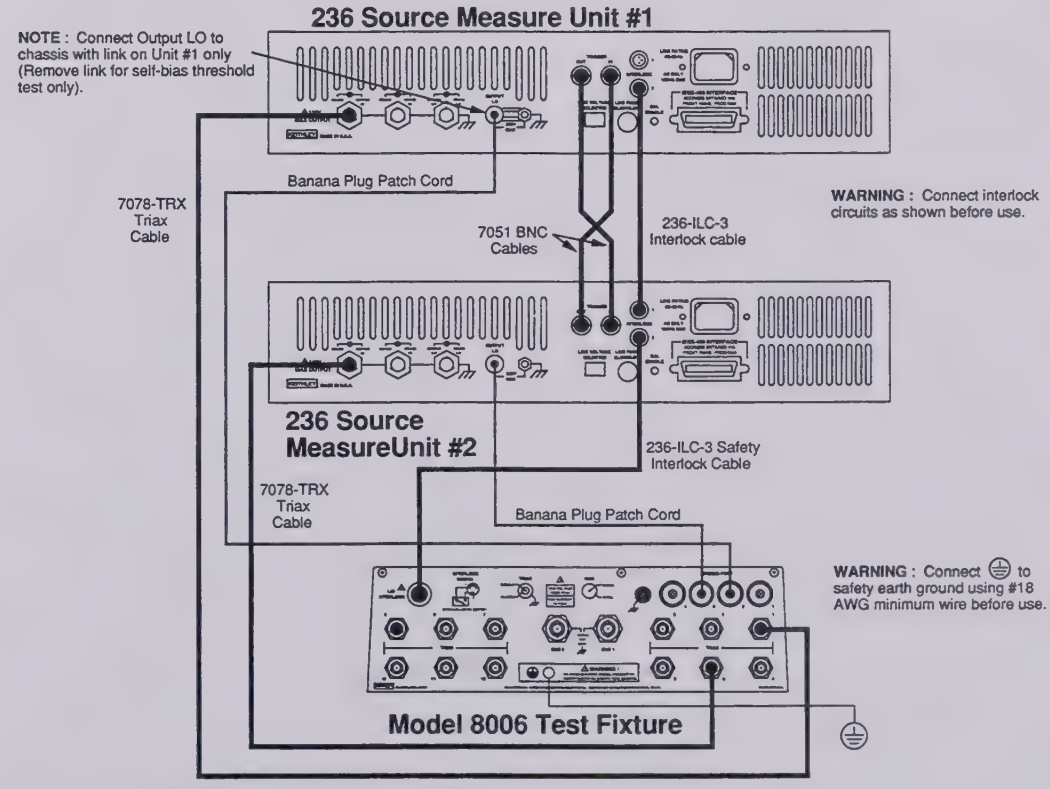

236 Source Measure Unit #1
NOTE : Connect Output LO to chassis with link on Unit #1 only (Remove link for self-bias threshold test only).
Banana Plug Patch Cord
7078-TRX Triax Cable
7051 BNC Cables
236-ILC-3 Interlock cable
WARNING : Connect interlock circuits as shown before use.
236 Source MeasureUnit #2
236-ILC-3 Safety Interlock Cable
7078-TRX Triax Cable
Banana Plug Patch Cord
WARNING : Connect ⏚ to safety earth ground using #18 AWG minimum wire before use.
Model 8006 Test Fixture

Figure 4-1. Instrument Connections for FET Tests

fore connecting or disconnecting wires or cables

Two final connections that must be made are the unit trigger connections. Connect the TRIGGER OUT jack of Unit #1 to the TRIGGER IN jack of Unit #2, and connect the TRIGGER OUT jack of Unit #2 to the TRIGGER IN jack of Unit #1. Use standard BNC-to-BNC cables such as the Model 7051 to make these connections.

NOTES

1. Remote sensing connections are recommended for optimum accuracy. See paragraph 1.2.2 for details.
2. If measurement noise is a problem, or for critical, low-level applications, use shielded cable for all signal connections.
3. The FET test programs use external triggering. If the trigger jacks are not connected as shown, the programs will not function properly.

4.3 JUMPER INSTALLATION FOR FET TESTS

Figure 4-2 shows jumper installation for the transistor tests. The FET itself should be placed in the appropriate four-terminal TO package socket, and the jumper connections should be made between the instrument panel jacks and the jacks on the component panel. Note that local sensing is used for most applications, so jumpers should be connected as shown.

4.4 COMMON-SOURCE CHARACTERISTICS

One of the more common FET tests involving family of curves are common-source characteristics. Such tests are very similar to the common-emitter characteristic tests outlined earlier except, of course, for the fact that an FET rather than a bipolar transistor is involved.

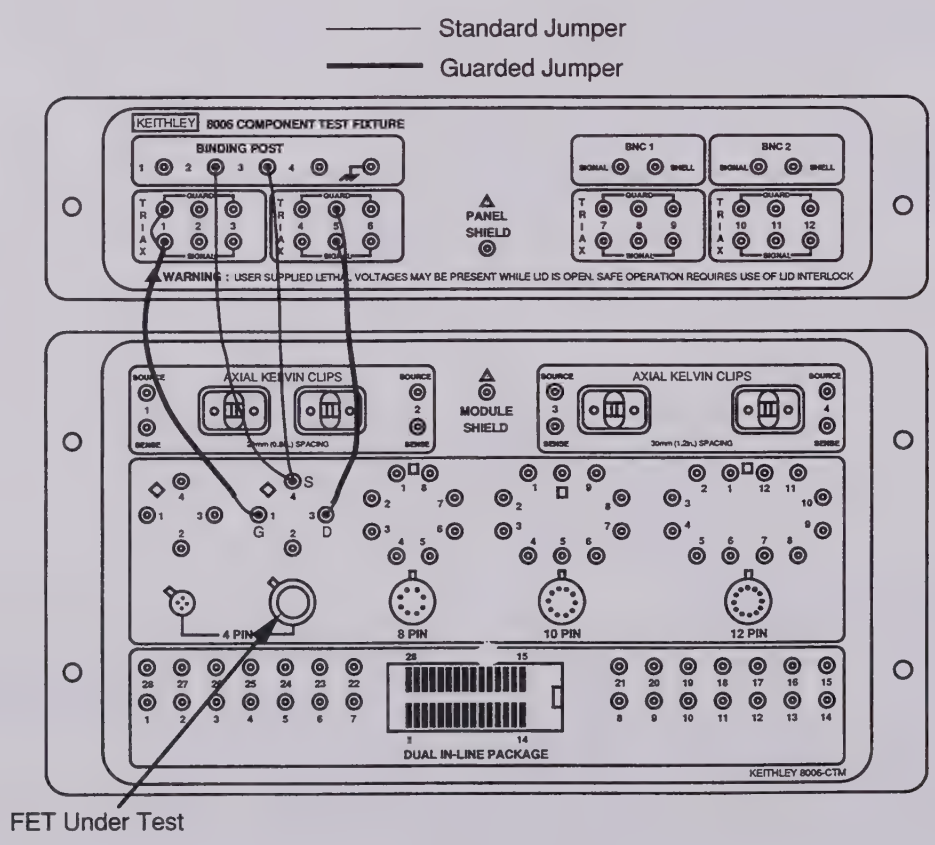


Figure 4-2. Jumper Installation for FET Tests

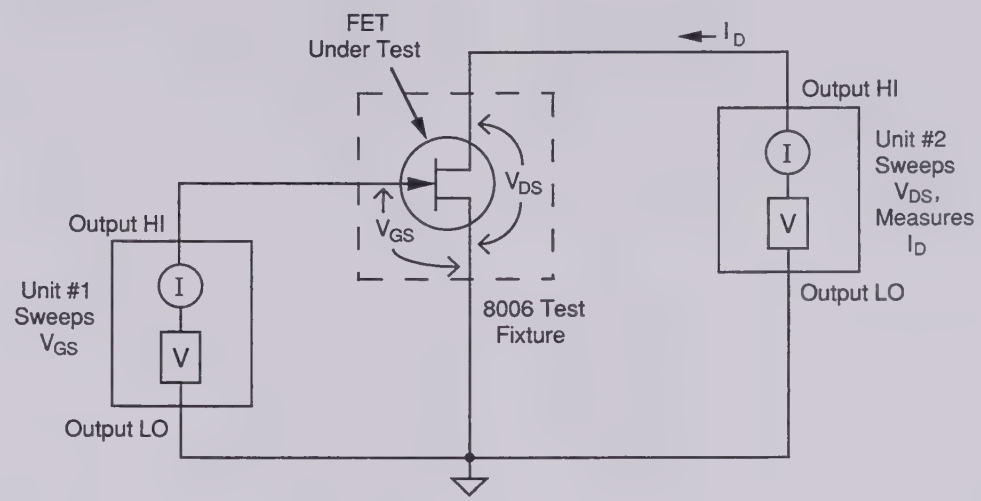


Figure 4-3. Test Configuration for Common-source Tests

Test data for common-source characteristics are obtained by sweeping the gate-source voltage, V_{GS}, across the desired range of values at specific increments. At each V_{GS} value, the drain-source voltage, V_{DS} is swept through the required range, once again at the desired increments. At each V_{DS} value, the drain current, I_D, is measured. Plots made from this data show I_D vs. V_{DS} with one curve for each value of V_{GS}.

4.4.1 Test Configuration

Figure 4-3 shows the test configuration for the common-source tests. Unit #1 sweeps V_{GS}, while Unit #2 sweeps V_{DS}, and the instrument also measures I_D. For this programming example, a small-signal, N-channel JFET such as a 2N4392 is recommended.

4.4.2 Program 9: Common-source Characteristics

Program 9 below outlines general programming techniques for measuring common-source characteristics. Follow the steps outlined below to use this program.

1. With the power off, connect both Source Measure Units to the IEEE-488 bus of the computer.
2. Connect both Source Measure Units to the test fixture using suitable triax cables (see Figure 4-1 for details on test connections).
3. Turn on both units, and allow them to warm up for at least two hours for rated accuracy. Verify that the primary address of Unit #1 is set to 16; the primary address of Unit #2 should be set to 17.
4. Turn on the computer, then boot up BASIC.
5. Enter the lines from Program 9 below into the computer.
6. Place a small-signal N-channel JFET such as a 2N4392 in the appropriate transistor socket. Install the correct jumpers, then close the test fixture lid.
7. RUN the program in the usual fashion. The computer will step through V_{GS} values between –2V and 0V using 0.5V steps. At each V_{GS} step, V_{DS} will be stepped between 0V and 10V at 0.1V increments. At each increment, I_D will be measured. Once data are collected, a plot of I_D vs. V_{DS} for each V_{GS} value will be displayed.
8. To return to BASIC from the graph, press CONT.

4.4.3 Typical Program 9 Results

Figure 4-4 shows a typical plot generated by example Program 9. A 2N4392 N-channel JFET was used to generate these curves.

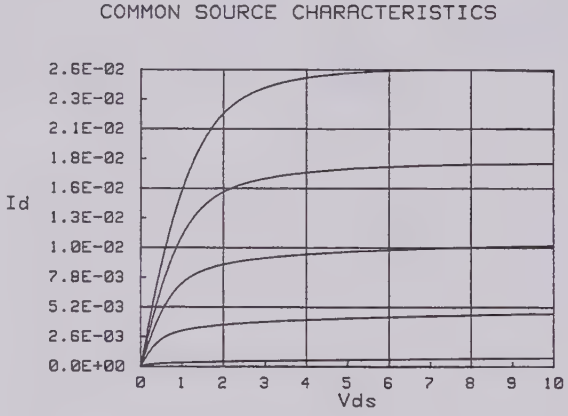


Figure 4-4. Example Plot Generated by Program 9

4.4.4 Program 9 Description

For the following description, refer to the Program 9 listing and the flowchart shown in Figure 4-5.

Initially, the array is set up for five sweeps of 101 data points each (lines 20 and 30), and the units are returned to default conditions (line 40). Next, Unit #1, which sweeps V_{GS}, is programmed as follows (lines 70-160):

- Source V, sweep mode
- 1mA compliance, 1mA range
- Local sense
- GET trigger, one trigger per point, output trigger end of delay
- Start V_{GS} voltage: –2V
- Stop V_{GS} voltage: 0V
- Step V_{GS} voltage: 0.5V
- Delay: 100msec
- Staircase sweep

Following Unit #1 setup, Unit #2, which sweeps V_{DS} and measures I_D, is configured as follows (lines 180-300):

- Source V, sweep mode
- Local sensing
- 100mA compliance, autorange measure

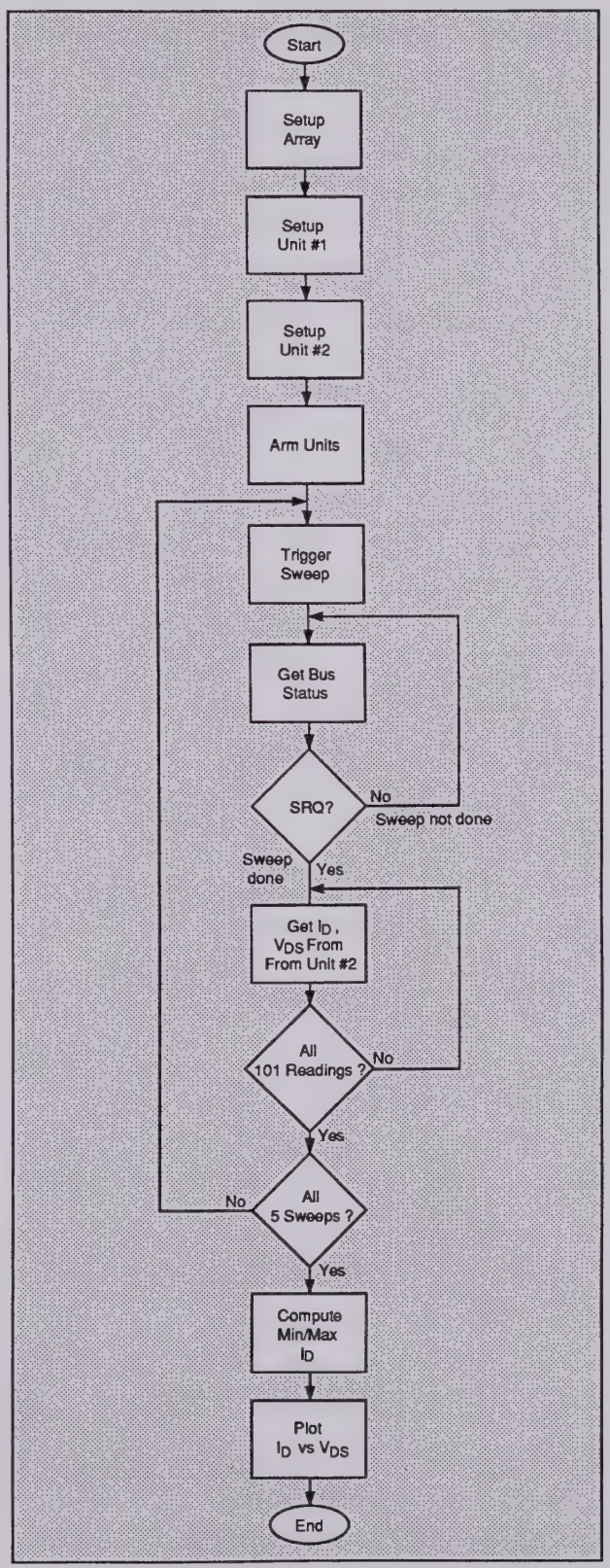


Figure 4-5. Program 9 Flowchart

- Source, measure data format, no prefix, sweep data output
- SRQ on sweep done
- External trigger, continuous
- Start V_{DS} voltage: 0V
- Stop V_{DS} voltage: 10V
- Step V_{DS} voltage: 0.1V
- Suppress enabled
- Line cycle integration
- Staircase sweep

Following setup of both units, the operator is prompted to begin the test (lines 310 and 320), and both units are armed and placed into operate (lines 330 and 340). Next, the program enters a loop to perform I_D vs. V_{DS} sweeps, one sweep for each value of V_{GS} (line 330).

Program 9 uses subordinate-sweep triggering to sequence through the sweeps. At the start of the main program loop, Unit #1 is GET triggered (line 370), at which point it sets its output to the current V_{GS} voltage step in the sweep list. At the end of the programmed delay period, Unit #1 outputs a trigger pulse that triggers Unit #2 via its external trigger input. Once triggered, Unit #2 goes through its sweep list of V_{DS} values, measuring and storing I_D along the way. Since suppress is enabled, the first reading of each sweep (at V_{DS} = 0V) will be stored as the suppress value, nulling any offset.

While the sweep is being processed, the program enters a loop that waits for an SRQ to occur (lines 380 and 390). After Unit #2 finishes its sweep, it generates the SRQ, and the program falls out of the loop and requests data from Unit #2 (lines 410-430). Note that V_{DS} data are placed into array elements (I,J,1), and measured I_D data are placed into array elements (I,J,2). Once data input has been completed, the program loops back to perform the next sweep (line 440). After all five sweeps are completed, both Source Measure Units are placed into standby (lines 450 and 460).

Next, an array search is performed to determine the maximum and minimum measured values of I_D (lines 500-570). Finally, the data are plotted with I_D along the Y axis, and V_{DS} along the X axis. Note that the graph is scaled according to the maximum and minimum V_{DS} values (X axis), and the maximum and minimum I_D values (Y axis).

4.4.5 Modifying Program 9

For other V_{GS} values, simply modify the Vgstart, Vgstop, and Vgstep variables as required (or use INPUT statements). For values that result in more or less than five sweeps, additional modifications to array size and corresponding loop counters must also be made.

Similarly, V_{DS} can be swept over a different range by changing the Vdstart, Vdstop, and Vdstep variables to the desired values (or, again add INPUT statements). The same general considerations regarding program modifications for array size and loop counter values also apply.

```
10    REM COMMON SOURCE CHARACTERISTIC TEST PROGRAM REV. 1.3 (Program 9)
20    OPTION BASE 1                    ! First array subscript is 1
30    DIM Reading(5,101,2)             ! Dimension reading array (5 swps,101 pts)
40    CLEAR 7                          ! Clear both Units
50    OUTPUT KBD;CHR$(255);CHR$(75);   ! Clear screen
60    REM ***** Unit 1 setup (sweeps Vgs) ****************************
70    REMOTE 716                       ! Put Unit 1 in remote
80    OUTPUT 716;"F0,1X"               ! Source V, sweep mode
90    OUTPUT 716;"L1E-3,7X"            ! 1mA compliance, 1mA range
100   OUTPUT 716;"O0X"                 ! Local sense
110   OUTPUT 716;"T1,1,2,0X"           ! GET trigger cycle,out trig end of delay
115   OUTPUT 716;"B0,0,0X"             ! Program 0 bias voltage
120   Vgstart=-2                       ! Define -2V start Vgs voltage
130   Vgstop=0                         ! Define 0V stop Vgs voltage
140   Vgstep=.5                        ! Define 0.5V step Vgs voltage
150   Dly=100                          ! Define 100msec Unit delay
160   OUTPUT 716;"Q1,";Vgstart;",";Vgstop;",";Vgstep;",0,";Dly;"X" ! Pgm swp
170   REM ***** Unit 2 setup (sweeps Vds, measures Id) ***************
180   REMOTE 717                       ! Put Unit 2 in remote
190   OUTPUT 717;"F0,1X"               ! Source V, sweep mode
200   OUTPUT 717;"O0X"                 ! Local sensing
210   OUTPUT 717;"L100E-3,0X"          ! 100mA compliance,autorange measure
220   OUTPUT 717;"G5,2,1X"             ! Source,measure,no prefix,sweep data
230   OUTPUT 717;"M2,X"                ! SRQ on sweep done
240   OUTPUT 717;"T3,0,0,0X"           ! Trigger on external,continuous
245   OUTPUT 717;"B0,0,0X"             ! Program 0 bias value
250   OUTPUT 717;"Z1X"                 ! Enable suppress
260   OUTPUT 717;"S2X"                 ! Line cycle integration
270   Vdstart=0                        ! Define 0V start Vds
280   Vdstop=10                        ! Define 10V stop Vds
290   Vdstep=.1                        ! Define 0.1V step Vds
300   OUTPUT 717;"Q1,";Vdstart;",";Vdstop;",";Vdstep;",0,";Dly;"X" ! Pgm swp
310   PRINT "Close lid, press CONT to begin test"
320   PAUSE
330   OUTPUT 716;"R1N1X"               ! Arm Unit 1 trigger,turn on output
340   OUTPUT 717;"R1N1X"               ! Arm Unit 2 trigger, turn on output
350   FOR I=1 TO 5                     ! Loop for five Vgs curves
360   PRINT "Generating sweep";I
370   TRIGGER 716                      ! Trigger Unit 1
380   STATUS 7,7;Stat                  ! Get IEEE-488 bus status
390   IF NOT BIT(Stat,10) THEN 380     ! Wait for Unit 2 SRQ on sweep done
400   Stat=SPOLL(717)                  ! Serial poll Unit 2 to clear SRQ
410   FOR J=1 TO 101                   ! Loop for all 101 readings
420   ENTER 717;Reading(I,J,1),Reading(I,J,2)! Get Vds and Id data from Unit 2
430   NEXT J                           ! Loop back for next reading
440   NEXT I                           ! Loop back for next Vgs value
450   OUTPUT 716;"N0X"                 ! Turn off Unit 1 output
460   OUTPUT 717;"N0X"                 ! Turn off Unit 2 output
470   PRINT "Press CONT to display graph"
480   PRINT "Press CONT while in graph to return to BASIC"
490   PAUSE
500   Ymin=MAXREAL                     ! Find minimum and maximum Id value
```

```
510   Ymax=-MAXREAL
520   FOR I=1 TO 5
530   FOR J=1 TO 101
540   IF Reading(I,J,2)<Ymin THEN Ymin=Reading(I,J,2)
550   IF Reading(I,J,2)>Ymax THEN Ymax=Reading(I,J,2)
560   NEXT J
570   NEXT I
580   OUTPUT KBD;CHR$(255);CHR$(75); ! Clear screen
590   GINIT                          ! Initialize graphics
600   PLOTTER IS CRT,"INTERNAL"      ! Define plot to CRT
610   GRAPHICS ON                    ! Turn on graphics
620   MOVE 20,95                     ! Title graph
630   LABEL "COMMON SOURCE CHARACTERISTICS"
640   MOVE 70,10                     ! Label X axis
650   LABEL "Vds"
660   MOVE 0,53                      ! Label Y axis
670   LABEL "Id"
680   VIEWPORT 30,120,20,85          ! Define soft clip limits
690   WINDOW Vdstart,Vdstop,Ymin,Ymax ! Scale graph
700   Y1=(Ymax-Ymin)/10              ! Compute Y axis increment
710   X1=(Vdstop-Vdstart)/10         ! Compute X axis increment
720   GRID 2*X1,2*Y1,Vdstart,Ymin    ! Draw grid
730   AXES X1,Y1,Vdstart,Ymin        ! Add some tick marks
740   FOR I=1 TO 5                   ! Loop for all five curves
750   FOR J=1 TO 101                 ! Loop for all 101 points per curve
760   PLOT Reading(I,J,1),Reading(I,J,2) ! Plot point
770   NEXT J                         ! Plot next point
780   PENUP                          ! Raise pen
790   NEXT I                         ! Plot next curve
800   CSIZE 4                        ! Define character size
810   LORG 6                         ! Center characters
820   CLIP OFF                       ! Turn off soft clip
830   FOR I=Vdstart TO Vdstop+.01*X1 STEP X1 ! Number X axis
840   MOVE I,Ymin-(Y1/4)
850   LABEL USING "#,K";I
860   NEXT I
870   FOR I=Ymin TO Ymax+.01*Y1 STEP Y1 ! Number Y axis
880   MOVE Vdstart-(1.3*X1),I+(.3*Y1)
890   LABEL USING "#,MD.DE";I
900   NEXT I
910   PAUSE
920   OUTPUT KBD;CHR$(255);CHR$(75); ! Clear alpha screen
930   GRAPHICS OFF                   ! Clear graphics screen
940   END
```

4.5 TRANSCONDUCTANCE TESTS

The forward transconductance, g_{fs}, of an FET is usually measured at a specific frequency (for example 1kHz). Such a test can be simulated with dc values by using as small an incremental change in dc parameters as possible. For example, assume that we source two gate-source voltages, V_{GS1} and V_{GS2}, and measure two resulting drain currents, I_{D1} and I_{D2}. The forward transconductance can then be approximated as follows:

$$g_{fs} \approx \frac{\Delta I_D}{\Delta V_{GS}}$$

Where: g_{fs} = forward transconductance (S)
$\Delta I_D = I_{D2} - I_{D1}$
$\Delta V_{GS} = V_{GS2} - V_{GS1}$

Two common plots involving g_{fs} include g_{fs} vs. V_{GS} and g_{fs} vs. I_D. The programming examples included in this section demonstrate how to generate g_{fs} vs. V_{GS} and g_{fs} vs. I_D plots.

4.5.1 Test Configuration

Figure 4-6 shows the general test configuration for transconductance tests. Unit #1 sweeps V_{GS}, while Unit #2 sources V_{DS} and also measures I_D. g_{fs} values are computed from incremental changes in I_D and V_{DS}. Note that a small-signal N-channel JFET such as a 2N4392 is recommended for use with the example program below.

4.5.2 Program 10: Transconductance vs. Gate Voltage Test

Use Program 10 below to generate a typical g_{fs} vs. V_{GS} plot.

1. With the power off, connect both Source Measure Units to the IEEE-488 bus of the computer.
2. Connect both Source Measure Units to the test fixture using suitable cables (see Figure 4-1 for details on test connections).
3. Turn on both Source Measure Units, and allow them to warm up for at least two hours for rated accuracy. Verify that the primary address of Unit #1 is set to 16; the primary address of Unit #2 should be set to 17.
4. Turn on the computer, then boot up BASIC.
5. Enter the lines from Program 10 below into the computer.
6. Place a small-signal N-channel JFET such as a 2N4392 in the appropriate transistor socket. Install the correct jumpers, then close the test fixture lid.
7. RUN the program in the usual fashion. The computer will step through V_{GS} values between –2V and 0V using 0.1V steps. At each increment, I_D will be measured using a fixed 10V V_{DS} value is used for the test. Once data are collected, a plot of g_{fs} vs. V_{GS} is displayed on the computer CRT.
8. To return to BASIC from the graph, press CONT.

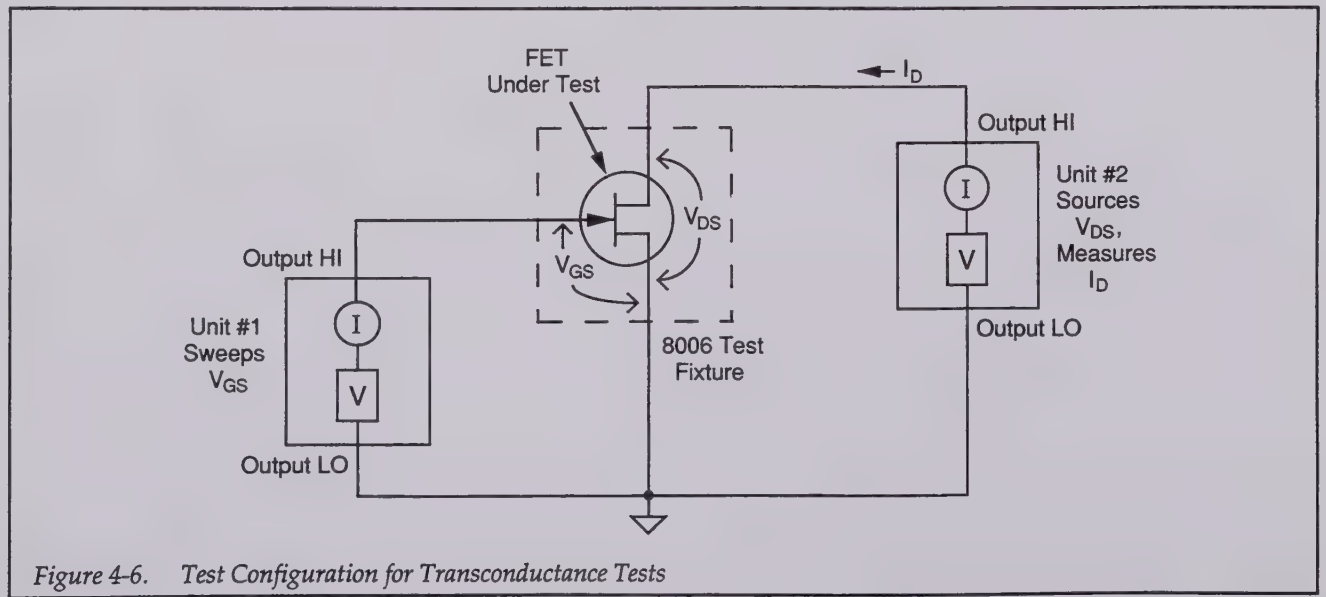


Figure 4-6. Test Configuration for Transconductance Tests

4.5.3 Typical Program 10 Results

Figure 4-7 shows a typical g_{fs} vs. V_{GS} plot as generated by the example program. Again, a 2N4392 N-channel JFET was used for the example plot.

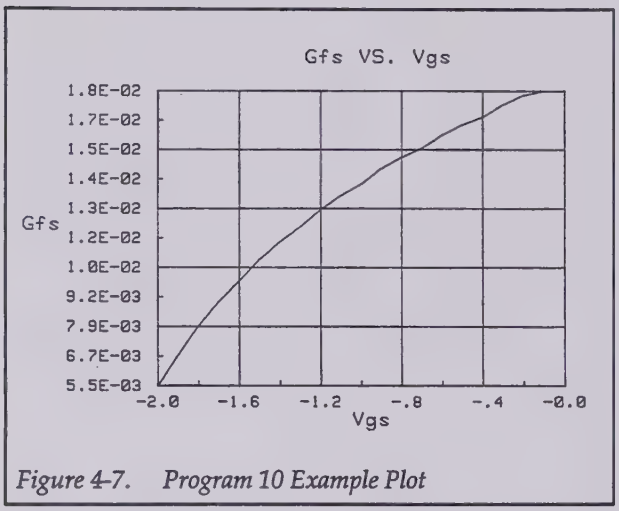


Figure 4-7. Program 10 Example Plot

4.5.4 Program 10 Description

Refer to the program listing below and the flowchart in Figure 4-8 for the following description of Program 10.

Initially, the data arrays are defined (lines 20-40) to hold 20 or 21 reading points. Note that two arrays are used in this program. The reading array will hold data obtained from the test instruments, while the plot array will hold computed g_{fs} and V_{GS} values to be plotted. After the instruments are returned to default conditions (line 50), Unit #1, which sweeps V_{GS}, is programmed as follows (lines 80-190):

- Source V, sweep mode
- 1mA compliance, 1mA range
- Local sense
- Source only data format, no prefix, sweep data output
- External trigger, one trigger per step, output trigger on end of measurement
- SRQ on sweep done
- Start V_{GS} voltage: –2V
- Stop V_{GS} voltage: 0V
- Step V_{GS} voltage: 0.1V
- Delay: 100msec
- Staircase sweep

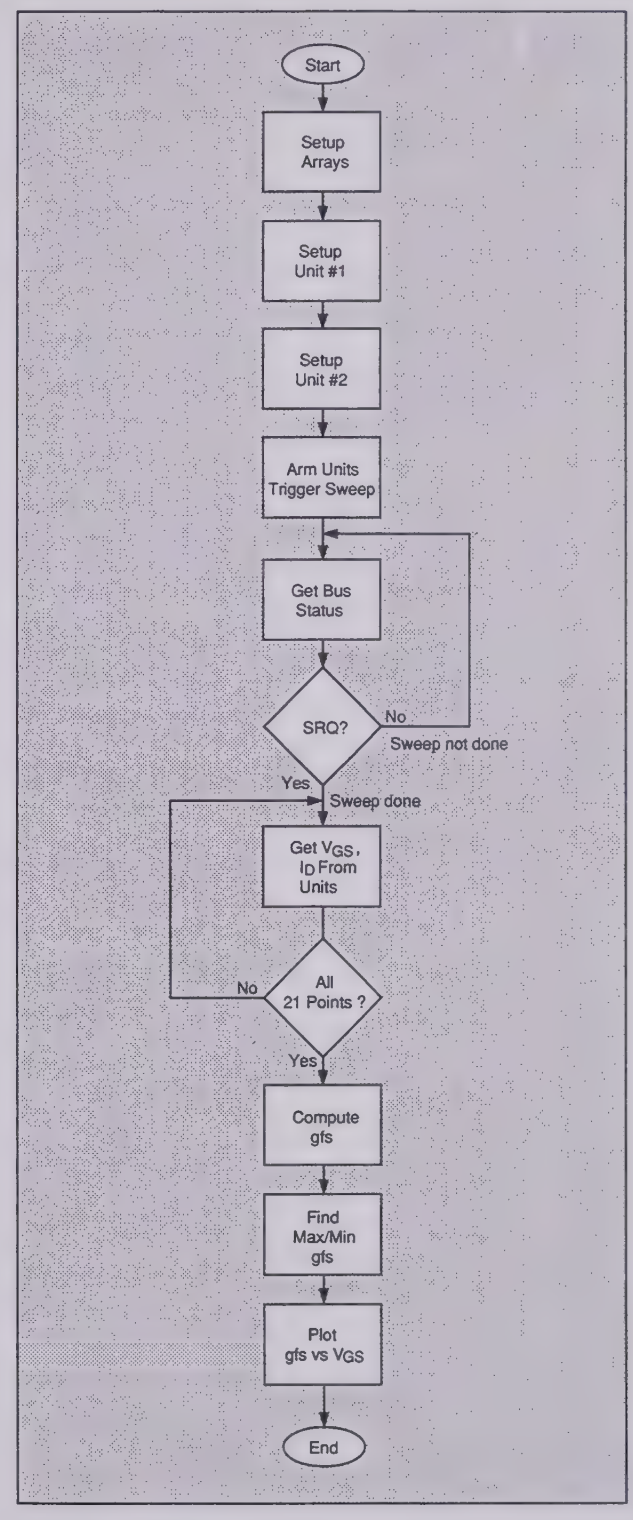


Figure 4-8. Program 10 Flowchart

Unit #2, which sources V_{DS} and measures I_D, is then configured in the following manner (lines 200-300):

- Source V, sweep mode
- Local sense
- 100mA compliance, autorange measure
- Measure only data format, no prefix, sweep data out
- External trigger, trigger source, output trigger on end of measurement
- Line cycle integration
- Delay: 100msec
- Constant sweep, 10V constant V_{DS} value, 21 points

After operator signal (lines 310 and 320), both units are armed and placed into operate (lines 330 and 340). Unit #1 is then triggered to start the sweep by using the immediate trigger command (line 360). Once Unit #1 is triggered, it sets V_{GS} to the programmed value, and it then triggers Unit #2 at the end of the measurement (using external triggering). Unit #2 then sets V_{DS} to the programmed value. Following the delay, Unit #2 measures I_D and it then triggers Unit #1 to go on to the next V_{GS} value. The process repeats until all points in the sweep have been taken.

While the sweep is being performed, the program waits in a loop for Unit #2 to generate an SRQ on sweep done (lines 370 and 380). Once the SRQ occurs, the data are read into the reading array (lines 400-430), and the Source Measure Units are placed into standby (lines 440 and 450). Note that the V_{GS} values are placed into array elements (I,1), and the I_D values are stored in array elements (I,2).

Next, we encounter the part of the program where the transconductance values are calculated (lines 500-550). First, the V_{GS} values are simply transferred from the (I,1) elements of the reading array to the (I,1) elements of the plot array (line 510). Next, ΔV_{GS} values are computed by subtracting the (I,1) values from the (I+1,1) values (line 520), and ΔI_D values are similarly computed by subtracting (I+1,2) values from (I,2) values (line 530). Finally, each transconductance value is computed from ΔI_D and ΔV_{GS} and stored in the corresponding element of the plot array (line 540).

The maximum and minimum transconductance values are then determined for Y axis scaling (lines 560-610), and the data are plotted with g_{fs} along the Y axis and V_{GS} along the X axis (lines 630-920).

```
10    REM TRANSCONDUCTANCE-GATE VOLTAGE TEST PROGRAM REV. 1.3 (Program 10)
20    OPTION BASE 1                    ! First array subscript is 1
30    DIM Reading(21,2)                ! Dimension reading array (21 points)
40    DIM Plot_array(20,2)             ! Dimension plot array (20 points)
50    CLEAR 7                          ! Clear both Units
60    OUTPUT KBD;CHR$(255);CHR$(75);   ! Clear screen
70    REM ***** Unit 1 setup (sweeps Vgs) ****************************
80    REMOTE 716                       ! Put Unit 1 in remote
90    OUTPUT 716;"F0,1X"               ! Source V, sweep mode
100   OUTPUT 716;"L1E-3,7X"            ! 1mA compliance,1mA range
110   OUTPUT 716;"O0X"                 ! Local sense
120   OUTPUT 716;"G1,2,1"              ! Output source,no prefix,sweep data
130   OUTPUT 716;"T3,1,4,0X"           ! External trigger,out trig end of measure
140   OUTPUT 716;"M2,X"                ! SRQ on sweep done
145   OUTPUT 716;"B0,0,0X"             ! Program 0 bias value
150   Vgstart=-2                       ! Define -2V start Vgs voltage
160   Vgstop=0                         ! Define 0V stop Vgs voltage
170   Vgstep=.1                        ! Define 0.1V step Vgs voltage
180   Dly=100                          ! Define 100msec Unit delay
190   OUTPUT 716;"Q1,";Vgstart;",";Vgstop;",";Vgstep;",0,";Dly;"X" ! Pgm swp
200   REM ***** Unit 2 setup (sources Vds, measures Id) ***************
210   REMOTE 717                       ! Put Unit 2 in remote
220   OUTPUT 717;"F0,1X"               ! Source V, sweep mode
230   OUTPUT 717;"O0X"                 ! Local sensing
240   OUTPUT 717;"L100E-3,0X"          ! 100mA compliance,autorange measure
250   OUTPUT 717;"G4,2,1X"             ! Measure,no prefix,sweep data
260   OUTPUT 717;"T3,1,4,0X"           ! Trig ext,start source,out end of meas
270   OUTPUT 717;"S2Z0X"               ! Line cycle integration,suppress off
275   OUTPUT 717;"B0,0,0X"             ! Program 0 bias value
280   Vds=10                           ! Define 10V Vds
290   Dly=100                          ! 100msec Unit 2 delay
300   OUTPUT 717;"Q0,";Vds;",0,";Dly;",21X" ! Constant sweep,21 points
310   PRINT "Close lid, press CONT to begin test"
320   PAUSE
330   OUTPUT 716;"R1N1X"               ! Arm Unit 1 trigger,turn on output
340   OUTPUT 717;"R1N1X"               ! Arm Unit 2 trigger, turn on output
350   PRINT "Generating sweep"
360   OUTPUT 716;"H0X"                 ! Trigger Unit 1 to start sweep
370   STATUS 7,7;Stat                  ! Get IEEE-488 bus status
380   IF NOT BIT(Stat,10) THEN 370     ! Wait for Unit 1 SRQ on sweep done
390   Stat=SPOLL(716)                  ! Serial poll Unit 1 to clear SRQ
400   FOR I=1 TO 21                    ! Loop for all 21 readings
410   ENTER 716;Reading(I,1)           ! Get Vgs data from Unit 1
420   ENTER 717;Reading(I,2)           ! Get Id data from Unit 2
430   NEXT I                           ! Loop back for next data point
440   OUTPUT 716;"N0X"                 ! Turn off Unit 1 output
450   OUTPUT 717;"N0X"                 ! Turn off Unit 2 output
460   PRINT "Press CONT to display graph"
470   PRINT "Press CONT while in graph to return to BASIC"
480   PAUSE
490   REM COMPUTE TRANSCONDUCTANCE AND STORE IN PLOT ARRAY
500   FOR I=1 TO 20                    ! Loop for all gfs points
```

```
510   Plot_array(I,1)=Reading(I,1)   ! Store Vgs in plot array
520   Delta_vgs=ABS(Reading(I+1,1)-Reading(I,1)) ! Compute delta Vgs
530   Delta_id=ABS(Reading(I+1,2)-Reading(I,2))  ! Compute delta Id
540   Plot_array(I,2)=Delta_id/Delta_vgs          ! Compute gfs
550   NEXT I                          ! Loop back for next point
560   Ymin=MAXREAL                    ! Find minimum and maximum gfs value
570   Ymax=-MAXREAL
580   FOR I=1 TO 20
590   IF Plot_array(I,2)<Ymin THEN Ymin=Plot_array(I,2)
600   IF Plot_array(I,2)>Ymax THEN Ymax=Plot_array(I,2)
610   NEXT I
620   OUTPUT KBD;CHR$(255);CHR$(75); ! Clear screen
630   GINIT                           ! Initialize graphics
640   PLOTTER IS CRT,"INTERNAL"       ! Define plot to CRT
650   GRAPHICS ON                     ! Turn on graphics
660   MOVE 60,90                      ! Title graph
670   LABEL "Gfs VS. Vgs"
680   MOVE 70,10                      ! Label X axis
690   LABEL "Vgs"
700   MOVE 0,53                       ! Label Y axis
710   LABEL "Gfs"
720   VIEWPORT 30,120,20,85           ! Define soft clip limits
730   WINDOW Vgstart,Vgstop,Ymin,Ymax ! Scale graph
740   Y1=(Ymax-Ymin)/10               ! Compute Y axis increment
750   X1=(Vgstop-Vgstart)/10          ! Compute X axis increment
760   GRID 2*X1,2*Y1,Vgstart,Ymin     ! Draw grid
770   AXES X1,Y1,Vgstart,Ymin         ! Add some tick marks
780   PLOT Plot_array(*)              ! Plot array
790   CSIZE 4                         ! Define character size
800   LORG 6                          ! Center characters
810   CLIP OFF                        ! Turn off soft clipping
820   FOR I=Vgstart TO Vgstop+.01*X1 STEP 2*X1 ! Number X axis
830   MOVE I,Ymin-(Y1/4)
840   LABEL USING "#,MD.D";I
850   NEXT I
860   FOR I=Ymin TO Ymax+.01*Y1 STEP Y1 ! Number Y axis
870   MOVE Vgstart-(1.3*X1),I+(.3*Y1)
880   LABEL USING "#,D.DE";I
890   NEXT I
900   PAUSE
910   OUTPUT KBD;CHR$(255);CHR$(75); ! Clear alpha screen
920   GRAPHICS OFF                    ! Clear graphics screen
930   END
```

4.5.5 Program 11: Transconductance vs. Drain Current Test

Use Program 11 below to generate a typical I_D vs. V_{GS} plot.

1. With the power off, connect both Source Measure Units to the IEEE-488 bus of the computer.
2. Connect both Source Measure Units to the test fixture using suitable triax cables (see Figure 4-1 for details on test connections).
3. Turn on both units, and allow them to warm up for at least two hours for rated accuracy. Verify that the primary address of Unit #1 is set to 16; the primary address of Unit #2 should be set to 17.
4. Turn on the computer, then boot up BASIC.
5. Enter the lines from Program 11 below into the computer.
6. Place a small-signal N-channel JFET such as a 2N4392 in the appropriate transistor socket. Install the correct jumpers, then close the test fixture lid.
7. RUN the program in the usual fashion. The computer will step through V_{GS} values between –2V and 0V using 0.1V steps. At each increment, I_D will be measured using a fixed 10V V_{DS} value is used for the test. Once data are collected, a plot of g_{fs} vs. I_D is displayed on the computer CRT.
8. To return to BASIC from the graph, press CONT.

4.5.6 Typical Program 11 Results

Figure 4-9 shows a typical g_{fs} vs. I_D plot as generated by the example program. Again, a 2N4392 N-channel JFET was used for the example plot.

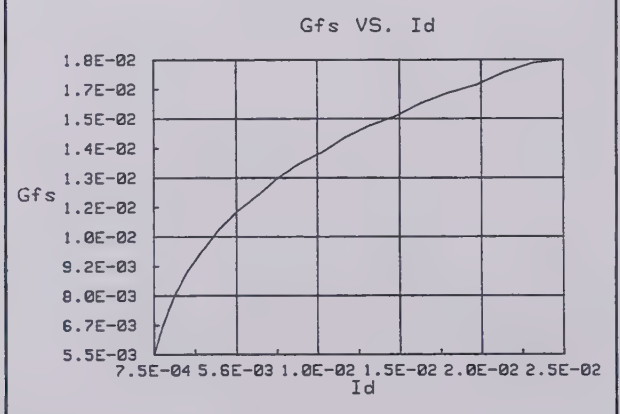


Figure 4-9. Program 11 Example Plot

4.5.7 Program 11 Description

Refer to the program listing below and the flowchart in Figure 4-10 for the following description of Program 11.

Initially, the data arrays are defined (lines 20-40) to hold 20 or 21 reading points. Once again, two arrays are used in this program. The reading array will hold data obtained from the test instruments, while the plot array will hold computed g_{fs} and I_D values to be plotted. After the instruments are returned to default conditions (line 50), Unit #1, which sweeps V_{GS}, is programmed as follows (lines 80-190):

- Source V, sweep mode
- 1mA compliance, 1mA range
- Local sense
- Source only data format, no prefix, sweep data output
- External trigger, one trigger per step, output trigger on end of measurement
- SRQ on sweep done
- Start V_{GS} voltage: –2V
- Stop V_{GS} voltage: 0V
- Step V_{GS} voltage: 0.1V
- Delay: 100msec
- Staircase sweep

Unit #2, which sources V_{DS} and measures I_D, is then configured in the following manner (lines 200-300):

- Source V, sweep mode
- Local sense
- 100mA compliance, autorange measure
- Source and measure data format, no prefix, sweep data output
- External trigger, trigger source, output trigger on end of measurement
- Delay: 100msec
- Constant sweep, 10V constant V_{DS} value, 21 points

After operator signal (lines 310 and 320), both units are armed and placed into operate (lines 330 and 340). Unit #1 is then triggered to start the sweep by using the immediate trigger command (line 360). Once Unit #1 is triggered, it sets V_{GS} to the programmed value, and it then triggers Unit #2 (using external triggering). Unit #2 then sets V_{DS} to the programmed value. Following the prescribed delay period, Unit #2 measures I_D and it then triggers Unit #1 to go on to the next V_{GS} value. The process repeats until all points in the sweep have been taken.

While the sweep is being performed, the program waits in a loop for Unit #2 to generate an SRQ on sweep done (lines 370 and 380). Once the SRQ occurs, the data are read into the reading array (lines 400-430), and the Source Measure Units are placed into standby (lines 440 and 450). Note that the V_{GS} values are placed into array elements (I,1), and the I_D values are stored in array elements (I,2).

Next, we encounter the part of the program where the transconductance values are calculated (lines 500-550). First, the I_D values are simply transferred from the (I,1) elements of the reading array to the (I,1) elements of the plot array (line 510). Next, ΔV_{GS} values are computed by subtracting the (I,1) values from the (I+1,1) values (line 520), and ΔI_D values are similarly computed by subtracting (I+1,2) values from (I,2) values (line 530). Finally, each transconductance value is computed from ΔI_D and ΔV_{GS} and stored in the corresponding element of the plot array (line 540).

The maximum and minimum transconductance values are then determined for Y axis scaling (lines 560-610), and the maximum and minimum I_D values are also computed (lines 620-670). Finally, data are plotted with g_{fs} along the Y axis and I_D along the X axis (lines 710-980).

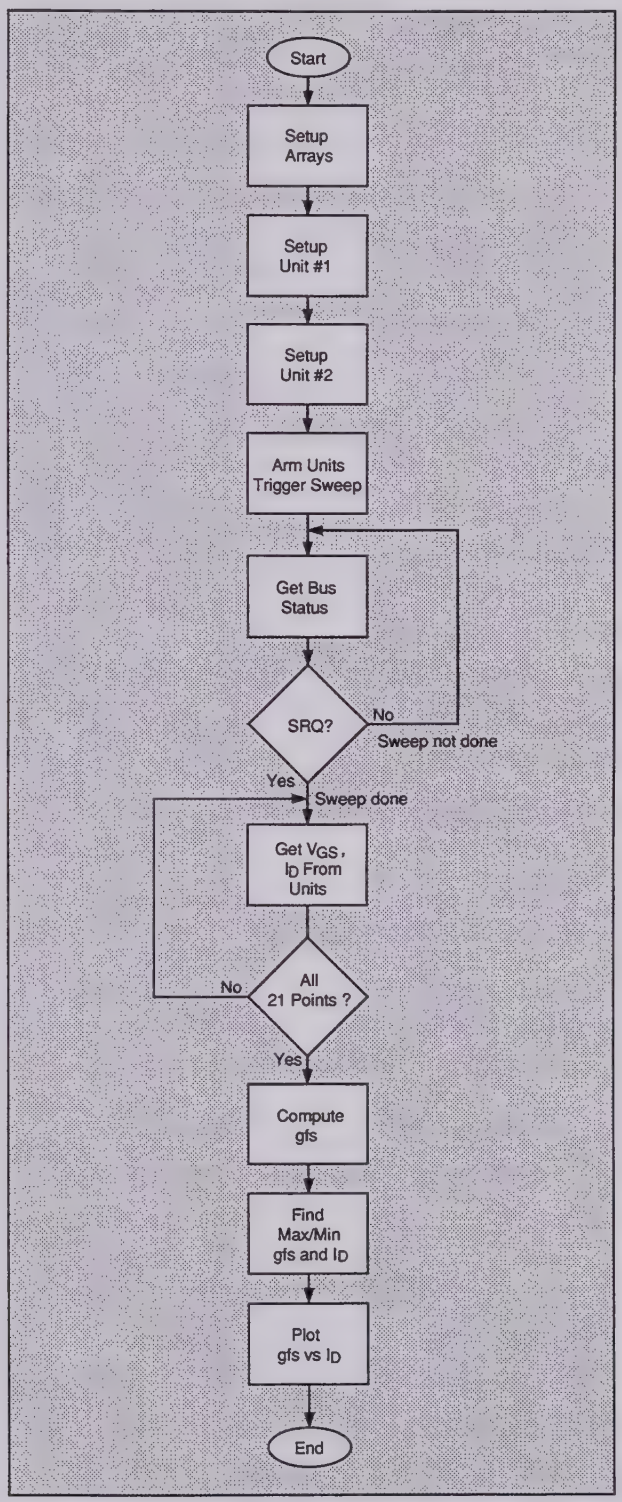


Figure 4-10. Program 11 Flowchart

```
10    REM TRANSCONDUCTANCE-DRAIN CURRENT TEST PROGRAM REV. 1.3 (Program 11)
20    OPTION BASE 1                    ! First array subscript is 1
30    DIM Reading(21,2)                ! Dimension reading array (21 points)
40    DIM Plot_array(20,2)             ! Dimension plot array (20 points)
50    CLEAR 7                          ! Clear both Units
60    OUTPUT KBD;CHR$(255);CHR$(75);   ! Clear screen
70    REM ***** Unit 1 setup (sweeps Vgs) ****************************
80    REMOTE 716                       ! Put Unit 1 in remote
90    OUTPUT 716;"F0,1X"               ! Source V, sweep mode
100   OUTPUT 716;"L1E-3,7X"            ! 1mA compliance, 1mA range
110   OUTPUT 716;"O0X"                 ! Local sense
120   OUTPUT 716;"G1,2,1"              ! Output source,no prefix,sweep data
130   OUTPUT 716;"T3,1,4,0X"           ! External trigger,out trig end of measure
140   OUTPUT 716;"M2,X"                ! SRQ on sweep done
145   OUTPUT 716;"B0,0,0X"             ! Program 0 bias value
150   Vgstart=-2                       ! Define -2V start Vgs voltage
160   Vgstop=0                         ! Define 0V stop Vgs voltage
170   Vgstep=.1                        ! Define .1V step Vgs voltage
180   Dly=100                          ! Define 100msec Unit delay
190   OUTPUT 716;"Q1,";Vgstart;",";Vgstop;",";Vgstep;",0,";Dly;"X" ! Pgm swp
200   REM ***** Unit 2 setup (sources Vds, measures Id) ***************
210   REMOTE 717                       ! Put Unit 2 in remote
220   OUTPUT 717;"F0,1X"               ! Source V, sweep mode
230   OUTPUT 717;"O0X"                 ! Local sensing
240   OUTPUT 717;"L100E-3,0X"          ! 100mA compliance,autorange measure
250   OUTPUT 717;"G4,2,1X"             ! Measure,no prefix,sweep data
260   OUTPUT 717;"T3,1,4,0X"           ! Trig ext,start source,out end of meas
270   OUTPUT 717;"S2Z0X"               ! Line cycle integration,suppress off
275   OUTPUT 717;"B0,0,0X"             ! Program 0 bias value
280   Dly=100                          ! 100msec Unit 2 delay
290   Vds=10                           ! Define 10V Vds
300   OUTPUT 717;"Q0,";Vds;",0,";Dly;",21X" ! Constant sweep,21 points
310   PRINT "Close lid, press CONT to begin test"
320   PAUSE
330   OUTPUT 716;"R1N1X"               ! Arm Unit 1 trigger,turn on output
340   OUTPUT 717;"R1N1X"               ! Arm Unit 2 trigger, turn on output
350   PRINT "Generating sweep"
360   OUTPUT 716;"H0X"                 ! Trigger Unit 1 to start sweep
370   STATUS 7,7;Stat                  ! Get IEEE-488 bus status
380   IF NOT BIT(Stat,10) THEN 370     ! Wait for Unit 1 SRQ on sweep done
390   Stat=SPOLL(716)                  ! Serial poll Unit 1 to clear SRQ
400   FOR I=1 TO 21                    ! Loop for all 21 readings
410   ENTER 716;Reading(I,1)           ! Get Vgs data from Unit 1
420   ENTER 717;Reading(I,2)           ! Get Id data from Unit 2
430   NEXT I                           ! Loop back for next data point
440   OUTPUT 716;"N0X"                 ! Turn off Unit 1 output
450   OUTPUT 717;"N0X"                 ! Turn off Unit 2 output
460   PRINT "Press CONT to display graph"
470   PRINT "Press CONT while in graph to return to BASIC"
480   PAUSE
490   REM COMPUTE TRANSCONDUCTANCE AND STORE IN PLOT ARRAY
500   FOR I=1 TO 20                    ! Loop for all gfs points
```

```
510   Plot_array(I,1)=Reading(I,2)   ! Store Id in plot array
520   Delta_vgs=ABS(Reading(I+1,1)-Reading(I,1)) ! Compute delta Vgs
530   Delta_id=ABS(Reading(I+1,2)-Reading(I,2))  ! Compute delta Id
540   Plot_array(I,2)=Delta_id/Delta_vgs         ! Compute gfs
550   NEXT I                          ! Loop back for next point
560   Ymin=MAXREAL                    ! Find minimum and maximum gfs value
570   Ymax=-MAXREAL
580   FOR I=1 TO 20
590   IF Plot_array(I,2)<Ymin THEN Ymin=Plot_array(I,2)
600   IF Plot_array(I,2)>Ymax THEN Ymax=Plot_array(I.2)
610   NEXT I
620   Xmin=MAXREAL                    ! Find minimum and maximum Id value
630   Xmax=-MAXREAL
640   FOR I=1 TO 20
650   IF Plot_array(I,1)<Xmin THEN Xmin=Plot_array(I,1)
660   IF Plot_array(I,1)>Xmax THEN Xmax=Plot_array(I,1)
670   NEXT I
680   OUTPUT KBD;CHR$(255);CHR$(75); ! Clear screen
690   GINIT                           ! Initialize graphics
700   PLOTTER IS CRT,"INTERNAL"       ! Define plot to CRT
710   GRAPHICS ON                     ! Turn on graphics
720   MOVE 60,90                      ! Title graph
730   LABEL "Gfs VS. Id"
740   MOVE 70,10                      ! Label X axis
750   LABEL "Id"
760   MOVE 0,53                       ! Label Y axis
770   LABEL "Gfs"
780   VIEWPORT 30,120,20,85           ! Define soft clip limits
790   WINDOW Xmin,Xmax,Ymin,Ymax      ! Scale graph
800   Y1=(Ymax-Ymin)/10               ! Compute Y axis increment
810   X1=(Xmax-Xmin)/10               ! Compute X axis increment
820   GRID 2*X1,2*Y1,Xmin,Ymin        ! Draw grid
830   AXES X1,Y1,Xmin,Ymin            ! Add some tick marks
840   PLOT Plot_array(*)              ! Plot array
850   CSIZE 4                         ! Define character size
860   LORG 6                          ! Center characters
870   CLIP OFF                        ! Turn off soft clipping
880   FOR I=Xmin TO Xmax+.01*X1 STEP 2*X1   ! Number X axis
890   MOVE I,Ymin-(Y1/4)
900   LABEL USING "#,MD.DE";I
910   NEXT I
920   FOR I=Ymin TO Ymax+.01*Y1 STEP Y1 ! Number Y axis
930   MOVE Xmin-(1.3*X1),I+(.3*Y1)
940   LABEL USING "#,D.DE";I
950   NEXT I
960   PAUSE
970   OUTPUT KBD;CHR$(255);CHR$(75); ! Clear alpha screen
980   GRAPHICS OFF                    ! Clear graphics screen
990   END
```

4.6 THRESHOLD TESTS

The threshold voltage, V_T, is a critical parameter for FET characterization as well as process control. Basically, there are a number of methods for determining V_T including several transconductance methods, the two point extrapolated V_T method, as well as the V_T @ I_D search method. In this paragraph, we will discuss the I_D search method for finding V_T along with a self-biasing method that takes advantage of the special capabilities of the Models 236 and 237.

4.6.1 Search Method Test Configuration

Figure 4-11 shows the general test configuration for the search method threshold voltage tests. Unit #1 sources V_{GS}, while Unit #2 sources V_{DS} and also measures I_D. An iterative search process is included in the program to allow you to enter a target I_D value.

4.6.2 Program 12A: Threshold Voltage Tests Using Search Method

Use Program 12A below to perform the V_T test using the search for target I_D method.

1. With the power off, connect both Source Measure Units to the IEEE-488 bus of the computer.
2. Connect both units to the test fixture using suitable triax cables (see Figure 4-1 for details on test connections).
3. Turn on both units, and allow them to warm up for at least two hours for rated accuracy. Verify that the primary address of Unit #1 is set to 16; the primary address of Unit #2 should be set to 17.
4. Turn on the computer, then boot up BASIC.
5. Enter the lines from Program 12 below into the computer.
6. Place the desired N-channel FET in the appropriate transistor socket. Install the correct jumpers, then close the test fixture lid.
7. RUN the program in the usual fashion. The computer will prompt you to enter two V_{GS} values which correspond to the V_{GS} variation range. Also, type in the desired fixed value for V_{DS} when prompted to do so. Finally, enter the target I_D value at which V_T is to be determined, and continue the program when ready to begin the test (typical I_D = 100μA).
8. The program will then step through the search process and attempt to match the drain current to the target value to within ±5% by varying V_{GS}. If more than 20 iterations are necessary, or if Unit #2 is found to be over compliance, you will be notified of that fact, and the program will halt.
9. If the search is successful, the value of V_{GS} which resulted in the target I_D value will then be displayed. This V_{GS} value is V_T. If the search is unsuccessful, rerun the program and choose a more appropriate set of V_{GS} values.

4.6.3 Program 12A Description

Refer to the program listing below and the flowchart in Figure 4-12 for the following description of Program 12A.

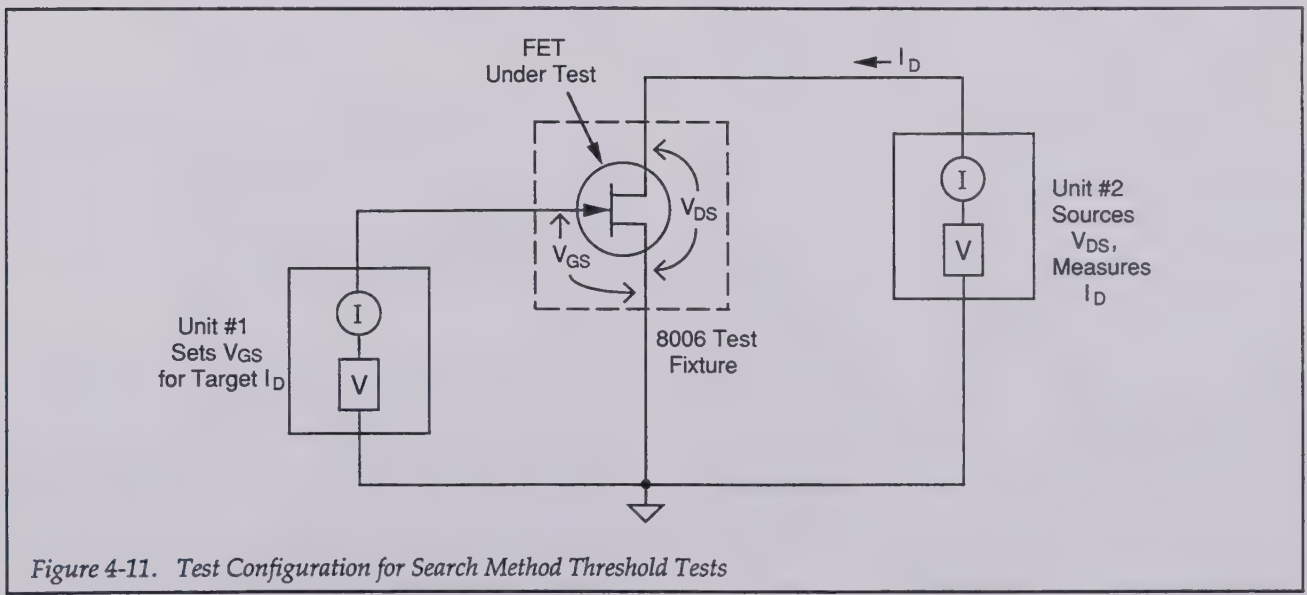


Figure 4-11. Test Configuration for Search Method Threshold Tests

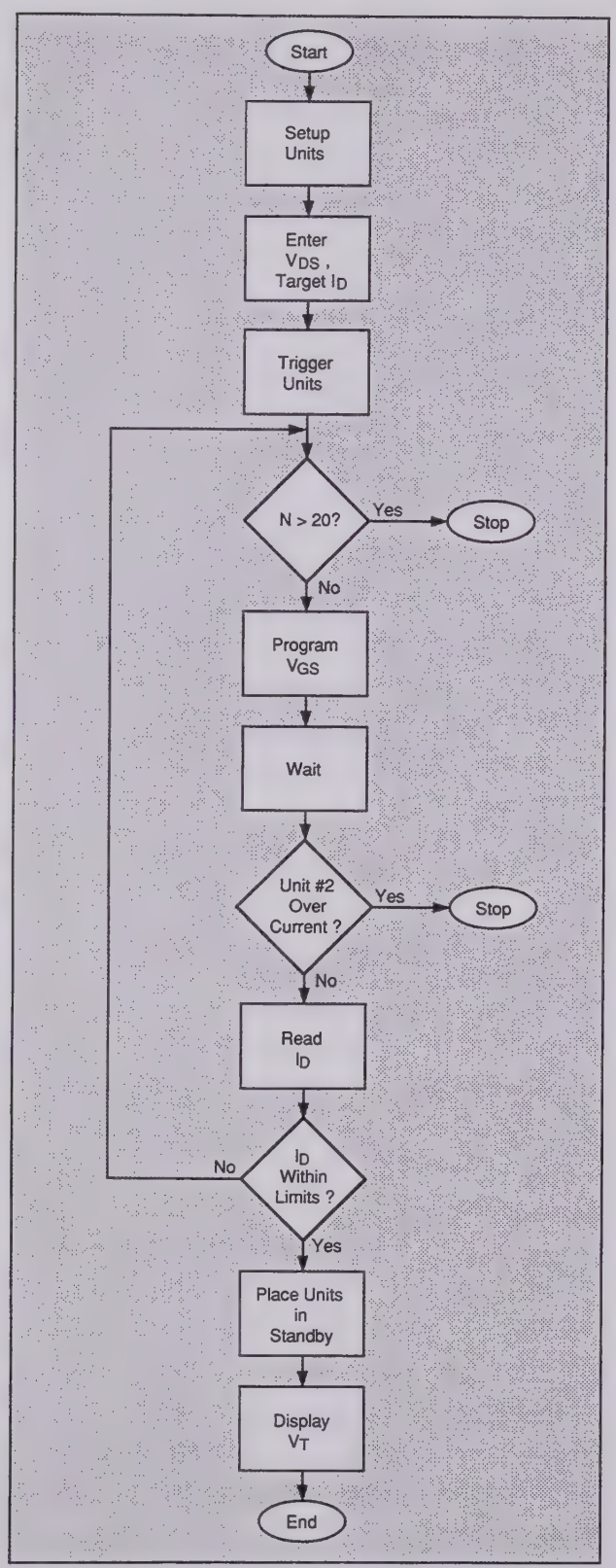


Figure 4-12. Program 12A Flowchart

Initially, the instruments are returned to default conditions (line 20), and the iteration variables are defined (lines 30 and 40). Next, Unit #1, which sources V_{GS}, is programmed as follows (lines 70-110):

- Source V, dc mode
- 1mA compliance, 1mA range
- Local sense
- Trigger on GET, continuous
- Delay: 1sec

Next, the range of V_{GS} values is entered, the the start value for V_{GS} is computed (lines 130-150). Unit #2, which sources V_{DS} and measures I_D, is then configured in the following manner (lines 170-260):

- Source V, dc mode
- Local sense
- 100mA compliance, autorange measure
- Measure only data format, no prefix, dc data output
- Trigger on GET, continuous
- Line cycle integration
- Bias value determined by user input

The desired V_{DS} and I_D values are then entered (lines 240 and 250), and, after operator signal (lines 270 and 280), both Source Measure Units are armed and placed into operate (lines 290 and 300) and finally triggered (lines 320 and 330). The iteration counter is then incremented and then checked against the maximum number of allow iterations (lines 340 and 350). If the iterative search exceeds the allowed limit, a message to that effect is displayed, and the program halts.

Assuming the number of iterations has not exceeded the allowed limit, Unit #1 is programmed with the presently-computed value of V_{GS} (line 400). After a one-second delay, Unit #2 is serial polled and its status byte is checked to determine whether or not the unit is over current compliance (lines 420 and 430). If so, an error message is displayed, and the program halts.

The program then requests a drain current reading (I_D) from Unit #2 (line 480), and then checks to see if the drain current value is close to the target I_D value (lines 490-580). If the I_D value is not within the required range (±5%), the program computes a new V_{GS} value and then loops back to perform the test loop again. Finally, both units are placed into standby (lines 590 and 600), and the V_T value at the actual I_D is displayed (line 610).

4.6.4 Modifying Program 12A

As written, the program sets the number of iterations to search for target I_D to 20 (line 30). You can change this variable to perform the iterative search as many times as is necessary. Similarly, the allowed range for the I_D target search is ±5%. Again, you can change this tolerance range as tight as necessary by modifying the limits in lines 490 and 540. Note that reducing the target range will probably require an increase in the number of iterations as well.

```
10    REM SEARCH METHOD THRESHOLD VOLTAGE TEST PROGRAM REV. 1.3 (Program 12A)
20    CLEAR 7                          ! Clear both Units
30    Iterations=20                    ! Define maximum search iterations
40    N=0                              ! Set iteration counter
50    OUTPUT KBD;CHR$(255);CHR$(75);   ! Clear screen
60    REM ***** Unit 1 setup (sources Vgs) ****************************
70    REMOTE 716                       ! Put Unit 1 in remote
80    OUTPUT 716;"F0,0X"               ! Source V, DC mode
90    OUTPUT 716;"L1E-3,7X"            ! 1mA compliance, 1mA range
100   OUTPUT 716;"O0X"                 ! Local sense
110   OUTPUT 716;"T1,0,0,0X"           ! GET trigger,continuous
120   Dly=1000                         ! Define 1 sec Unit delay
130   INPUT "Enter more positive Vgs",Vgs1 ! Input greater Vgs
140   INPUT "Enter more negative Vgs",Vgs2 ! Input lesser Vgs
150   Vgs=(Vgs1-Vgs2)/2+Vgs2           ! Compute start Vgs
160   REM ***** Unit 2 setup (sources Vds, measures Id) ***************
170   REMOTE 717                       ! Put Unit 2 in remote
180   OUTPUT 717;"F0,0X"               ! Source V, DC mode
190   OUTPUT 717;"O0M128,0X"           ! Local sensing,SRQ
200   OUTPUT 717;"L100E-3,0X"          ! 100mA compliance,autorange measure
210   OUTPUT 717;"G4,2,0X"             ! Measure,no prefix,DC data
220   OUTPUT 717;"S2Z0X"               ! Line cycle integration,suppress off
230   OUTPUT 717;"T1,0,0,0X"           ! Trigger on GET,continuous
240   INPUT "Enter Vds",Vds            ! Input Vds
250   INPUT "Enter target Id",Itarget  ! Input target Id for search
260   OUTPUT 717;"B";Vds;",0,";Dly;"X" ! Program DC,autorange,delay
270   PRINT "Close lid, press CONT to begin test"
280   PAUSE
290   OUTPUT 716;"R1N1X"               ! Arm Unit 1 trigger,turn on output
300   OUTPUT 717;"R1N1X"               ! Arm Unit 2 trigger,turn on output
310   PRINT "Measuring..."
320   TRIGGER 716                      ! Trigger Unit 1
330   TRIGGER 717                      ! Trigger Unit 2
340   N=N+1                            ! Increment iteration counter
350   IF N>Iterations THEN             ! Check for maximum iterations
360   BEEP
370   PRINT "More than";Iterations;"iterations"
380   STOP
390   END IF
400   OUTPUT 716;"B";Vgs;",0,";Dly;"X" ! Program Unit 1 Vgs value
410   WAIT Dly/1000+1                  ! Wait for settling
420   Stat=SPOLL(717)                  ! Serial poll Unit 2
430   IF BIT(Stat,7) THEN              ! Check for over compliance
440   BEEP
450   PRINT "Unit 2 is over current compliance"
460   STOP
470   END IF
480   ENTER 717;Id                     ! Get Id reading from Unit 2
490   IF Id>1.05*Itarget THEN          ! Check for Id > target
500   Vgs1=Vgs
```

```
510   Vgs=Vgs-(Vgs-Vgs2)/20
520   GOTO 340
530   END IF
540   IF Id<.95*Itarget THEN          ! Check for Id < target
550   Vgs2=Vgs
560   Vgs=Vgs+(Vgs1-Vgs)/20
570   GOTO 340
580   END IF
590   OUTPUT 716;"N0X"                ! Turn off Unit 1 output
600   OUTPUT 717;"N0X"                ! Turn off Unit 2 output
610   PRINT "Vt=";Vgs;"V @ Id=";Id    ! Display threshold voltage
620   END
```

4.6.5 Self-bias Threshold Test Configuration

Figure 4-13 shows the general test configuration for the self-bias method of threshold voltage tests. Unit #1 sources the drain current (assumed to be the same as the source current), and it also measures the threshold voltage, V_T. Unit #2 sources V_{DS}. This arrangement allows very rapid threshold voltage measurement (milliseconds per reading) at very low currents, and it can be used with both enhancement-mode and depletion-mode FETs. Note that the high-impedance sensing circuits and the floating capabilities of the Models 236/237 are key characteristics that allow this special configuration to be used.

WARNING

When a Model 236/237 is programmed for remote sensing, hazardous voltage may be present on the SENSE and OUTPUT terminals when the unit is in operate regardless of the programmed voltage or current. To avoid a possible shock hazard, always turn off power before connecting or disconnecting cables to the Source Measure Unit or the associated test fixture.

NOTE

Both V_{DS} and I_D must be programmed with reversed polarity because of the connection configuration used. For example, for an N-channel FET, both V_{DS} and I_D must be negative. These values will result in proper biasing of the DUT. Also, the sign of the measured V_T value will be reversed.

4.6.6 Self-bias Method Measurement Considerations

There is a limit as to the maximum voltage that can appear between the sense and source leads of each Source Measure Unit. For that reason, the maximum threshold voltage that can be measured with this method is defined as follows:

$$V_{MAX} = 12 - 10\left(\frac{V_{DS}}{V_{FS}}\right)$$

Where: V_{MAX} = maximum threshold voltage
V_{DS} = V_{DS} sourced by Unit 2
V_{FS} = full scale voltage of Unit 2

For example, if V_{DS} has a value of 5V with the unit on the 11V measurement range, the maximum voltage is:

$$V_{MAX} = 12 - 10(5/11) = 7.45V$$

From this relationship, it can be seen that the voltage range of Unit #2 should be set as high as possible.

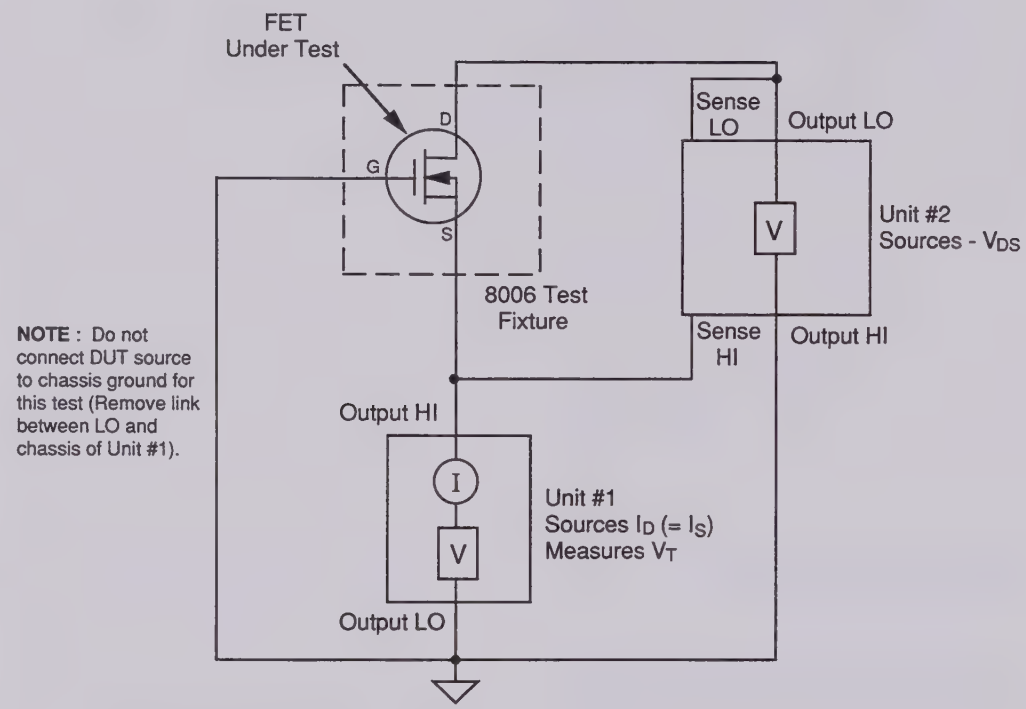


Figure 4-13. Test Configuration for Self-Bias Threshold Tests

4.6.7 Program 12B: Self-bias Threshold Voltage Tests

Use Program 12B below to perform the self-bias threshold voltage test.

1. With the power off, connect both Source Measure Units to the IEEE-488 bus of the computer.
2. Connect both units to the test fixture with suitable triax cables using Figure 4-13 as a guide. Note that remote sensing connections are used for Unit #2, and that both OUTPUT LO and SENSE LO of Unit #2 are connected to the drain of the device under test. With this configuration, it will be necessary to program negative V_{DS} and I_D values in order to properly bias the DUT.
3. Turn on both units, and allow them to warm up for at least two hours for rated accuracy. Verify that the primary address of Unit #1 is set to 16; the primary address of Unit #2 should be set to 17.
4. Turn on the computer, then boot up BASIC.
5. Enter the lines from Program 12B below into the computer.
6. Place the desired N-channel (enhancement-mode or depletion-mode) FET in the appropriate transistor socket. Install the correct jumpers (using Figure 4-13 as a guide), then close the test fixture lid.
7. RUN the program in the usual fashion. The computer will program Unit #1 to step through I_D current values between –10µA and –100µA at –10µA increments, using a 0msec user delay for maximum speed and a fixed V_{DS} value of –10V.
8. After data are collected, the computer will display the V_T values at the 10 tested I_D currents on the computer CRT. Both I_D and V_T values will be sign-adjusted for correct displayed polarity.

4.6.8 Program 12B Description

Refer to the program listing below and the flowchart in Figure 4-14 for the following description of Program 12B.

Initially, the instruments are returned to default conditions (line 20). Next, Unit #1, which sources I_D and measures V_T, is programmed as follows (lines 50-170):

- Source I, sweep mode
- 10V compliance, 11V range
- Local sense
- Trigger on GET, continuous

- Source, measure data, no prefix or suffix, sweep data
- SRQ on sweep done
- Fastest integration rate, filter off
- Start ID current: –10μA
- Stop ID current: –100μA
- Step ID current: –10μA
- Delay: 0msec

Next, Unit #2, which sources V_{DS} is then configured in the following manner (lines 190-250):

- Source V, DC mode
- Remote sensing
- 100mA compliance, 100mA range
- Trigger on GET, continuous
- –10V fixed V_{DS} value

After operator signal (lines 260 and 270), both Source Measure Units are armed and placed into operate (lines 280 and 290) and triggered (lines 300 and 310). The program then enters a loop to wait for Unit #1 to generate an SRQ (lines 320 and 330). After the SRQ, Unit #1 is serial polled to clear the SRQ (line 340), and both units are placed into standby (lines 350 and 360). The ten V_T values are then read from Unit #1 and displayed on the computer CRT (lines 380-430). Note that both I_D and V_T values are corrected for proper polarity.

4.6.9 Modifying Program 12B

As written, the program tests for threshold voltages at 10 values of I_D between –10μA and –100μA at –10μA increments (as pointed out previously, the programmed drain currents must be negative with an N-channel device because of the test configuration used). These values can be changed to the required values simply by modifying the corresponding variables in the program. Also, plotting routines from another program could be adapted and added to generate a plot of V_T vs. I_D. Paragraph 8.5 demonstrates V_T vs. I_D plotting.

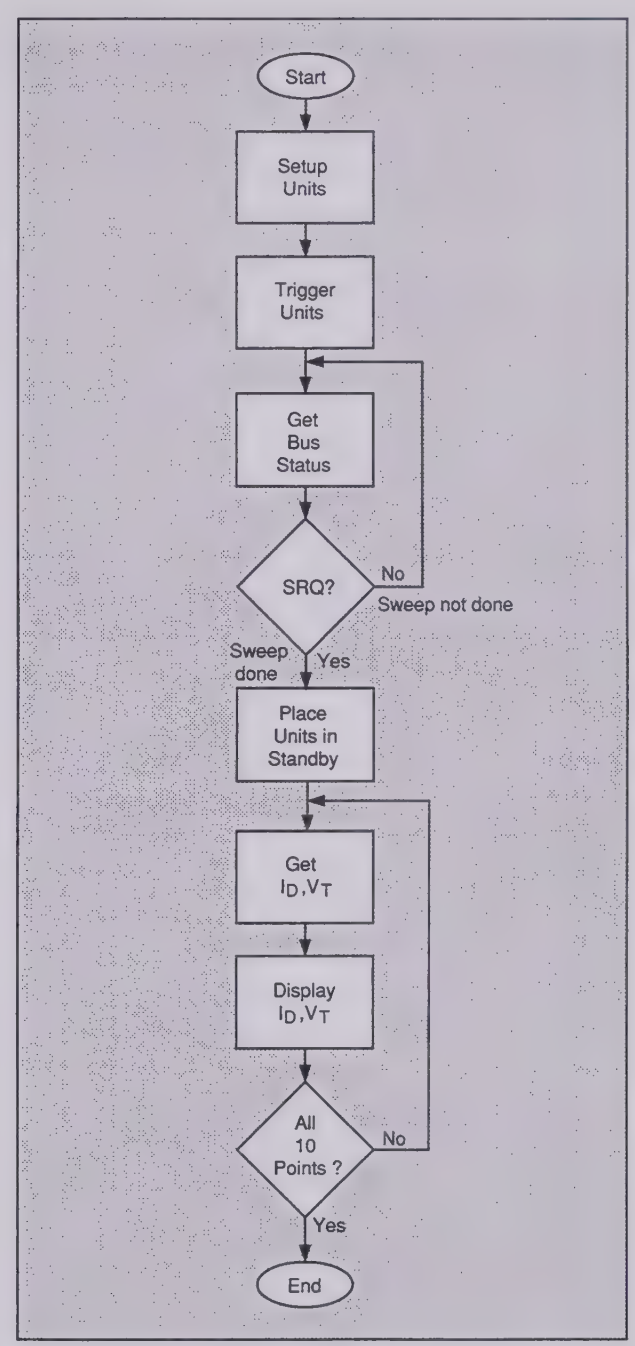


Figure 4-14. Program 12B Flowchart

```
10    REM SELF BIAS THRESHOLD VOLTAGE TEST PROGRAM REV. 1.3 (Program 12B)
20    CLEAR 7                          ! Clear both Units
30    OUTPUT KBD;CHR$(255);CHR$(75);   ! Clear screen
40    REM ***** Unit 1 setup (sources -Id, measures -Vt) ***************
50    REMOTE 716                       ! Put Unit 1 in remote
60    OUTPUT 716;"F1,1X"               ! Source I, sweep mode
70    OUTPUT 716;"L10,2X"              ! 10V compliance, 11V range
80    OUTPUT 716;"O0Z0X"               ! Local sense,suppress off
90    OUTPUT 716;"T1,0,0,0X"           ! GET trigger,continuous
100   OUTPUT 716;"G5,2,1X"             ! Source data,no prefix,sweep data
110   OUTPUT 716;"M2,X"                ! SRQ on sweep done
120   OUTPUT 716;"S0P0X"               ! Fast integration, filter off
125   OUTPUT 716;"B0,0,0X"             ! Program 0 bias value
130   Istart=-1.0E-5                   ! Define -10uA start current
140   Istop=-1.00E-4                   ! Define -100uA stop current
150   Istep=-1.0E-5                    ! Define -10uA step current
160   Dly=0                            ! Define 0 sec Unit delay
170   OUTPUT 716;"Q1,";Istart;",";Istop;",";Istep;",0,";Dly;"X" ! Pgm swp
180   REM ***** Unit 2 setup (sources -Vds) ****************************
190   REMOTE 717                       ! Put Unit 2 in remote
200   OUTPUT 717;"F0,0X"               ! Source V, DC mode
210   OUTPUT 717;"O1X"                 ! Remote sensing
220   OUTPUT 717;"L100E-3,9X"          ! 100mA compliance,100mA range
230   OUTPUT 717;"T1,0,0,0X"           ! Get trigger, continuous
240   Vds=-10                          ! Define -10V Vds value
250   OUTPUT 717 ;"B";Vds;",3,";Dly;"X"  ! Program DC, 110V range,delay
260   PRINT "Close lid, press CONT to begin test"
270   PAUSE
280   OUTPUT 716;"R1N1X"               ! Arm Unit 1 trigger,turn on output
290   OUTPUT 717;"R1N1X"               ! Arm Unit 2 trigger,turn on output
300   TRIGGER 717                      ! Trigger Unit 2
310   TRIGGER 716                      ! Trigger Unit 1
320   STATUS 7,7;Stat                  ! Get bus status
330   IF NOT BIT(Stat,10) THEN 320     ! Wait for SRQ
340   Stat=SPOLL(716)                  ! Serial poll Unit 1 to clear SRQ
350   OUTPUT 716;"N0X"                 ! Turn off Unit 1 output
360   OUTPUT 717;"N0O0X"               ! Turn off Unit 2 output,local sense
370   PRINT
380   PRINT "Id","Vt"
390   PRINT "----------------------"
400   FOR I=1 TO 10                    ! Loop for all 10 readings
410   ENTER 716;Id,Vt                  ! Get reading
420   PRINT -Id,-Vt                    ! Print reading, adjust signs
430   NEXT I
440   END
```

SECTION 5
Using Substrate Bias

5.1 INTRODUCTION

Thus far in this manual, we have concentrated on performing tests on devices that do not require substrate bias. Since many devices, especially those in complex packages, do require some form of substrate bias, our discussion would not be complete without discussing methods for applying and programming substrate bias.

In the following paragraphs, we will discuss two methods of applying substrate bias: (1) adding an additional Model 236/237 Source Measure Unit, and (2) using a Model 230 Programmable Voltage Source

5.2 SUBSTRATE BIAS INSTRUMENT CONNECTIONS

WARNING

Interlock circuits must be connected before use. Connect fixture ⏚ to safety earth ground using #18 AWG minimum wire before use. Turn off all power before connecting or disconnecting wires or cables.

5.2.1 Source Measure Unit Substrate Bias Connections

Figure 5-11 shows test connections when using an additional Source Measure Unit to apply substrate bias. Unit #1 and Unit #2 perform the same functions as outlined earlier in this section, and Unit #3 is used to apply substrate bias. Once again, the Model 8006 Component Test Fixture is recommended for test connections, along with Model 7078-TRX-3 triax cables. Note that the connecting cables to Unit #3 assume that local sensing will be used even though that may not be the situation in many cases.

5.2.2 Voltage Source Substrate Bias Connections

Figure 5-2 shows bias connections using a Model 230 Programmable Voltage Source for substrate bias connections. The two Source Measure Units are connected to the Model 8006 test fixture using Model 7078-TRX-3 triax cables just as before. The Model 230 Voltage Source is connected to two of the binding posts on the test fixture using banana plug patch cords. Note that remote sensing is not used in this application; remote sensing could be added by connecting the sense terminals of the voltage source to the two remaining binding posts on the test fixture.

NOTES

1. Remote sensing connections are recommended for optimum accuracy. See paragraph 1.2.2 for details.
2. If measurement noise is a problem, or for critical, low-level applications, use shielded cable for all signal connections.

5.3 SUBSTRATE BIAS JUMPER CONNECTIONS

If you are using the Model 8006 test fixture, you must install appropriate jumpers to complete bias connections (jumpers must also be installed for remaining device connections as outlined earlier in this manual). The exact jumper configuration will, of course, depend on the type of device packages you intend to use for the programming examples in this section.

5.4 SOURCE MEASURE UNIT SUBSTRATE BIASING

The following paragraphs discuss using a Model 236/237 Source Measure Unit to provide substrate biasing. In the first example, the substrate current, I_{SB}, is measured as the gate-source voltage, V_{GS} is swept across the desired range. A plot of I_{SB} vs. V_{GS} is generated by the program. In the second example, the third Source Measure Unit provides substrate bias for common-source characteristic tests.

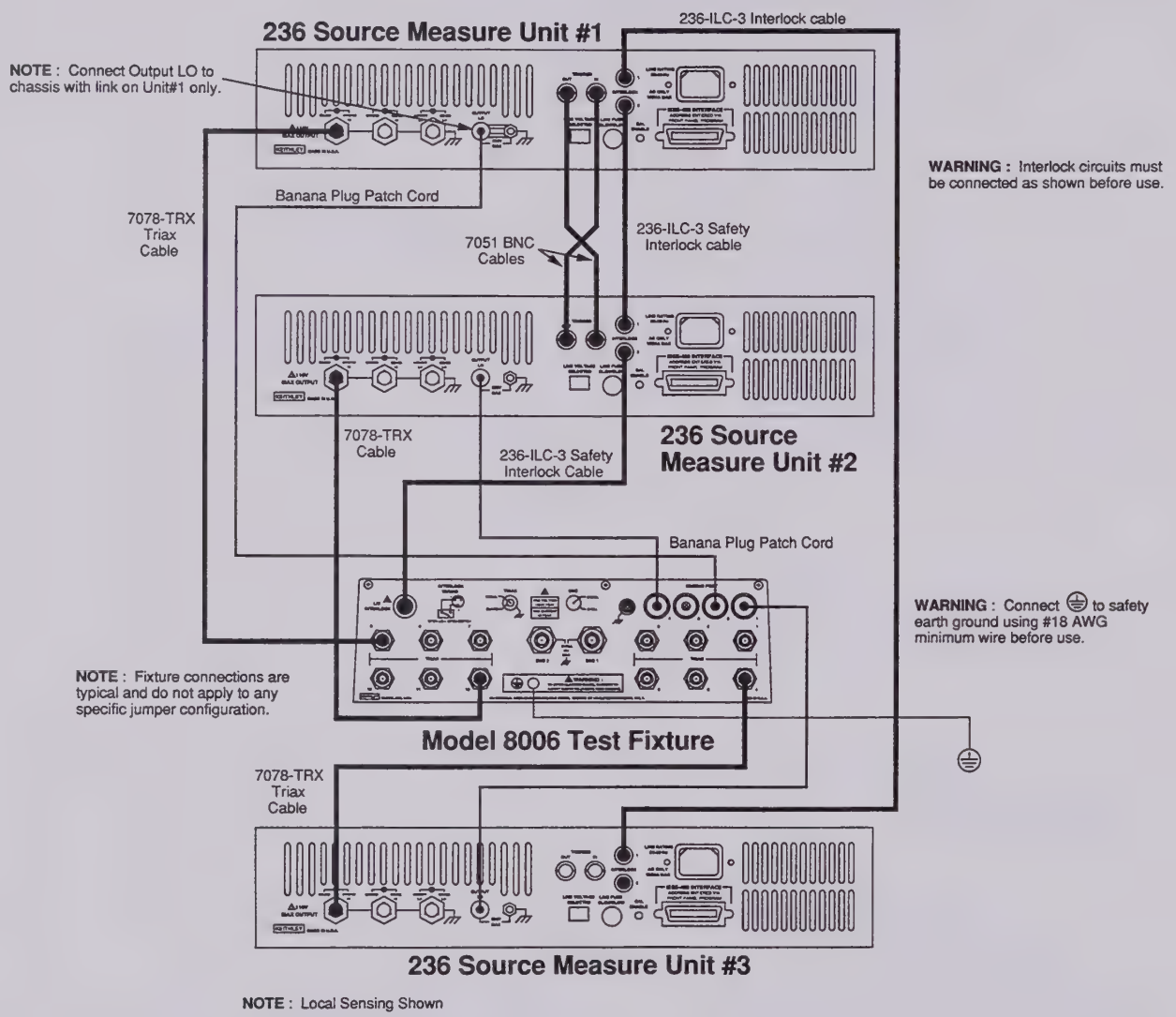

236 Source Measure Unit #1
236-ILC-3 Interlock cable
NOTE : Connect Output LO to chassis with link on Unit#1 only.
WARNING : Interlock circuits must be connected as shown before use.
Banana Plug Patch Cord
7078-TRX Triax Cable
7051 BNC Cables
236-ILC-3 Safety Interlock cable
7078-TRX Cable
236-ILC-3 Safety Interlock Cable
236 Source Measure Unit #2
Banana Plug Patch Cord
WARNING : Connect ⏚ to safety earth ground using #18 AWG minimum wire before use.
NOTE : Fixture connections are typical and do not apply to any specific jumper configuration.
Model 8006 Test Fixture
7078-TRX Triax Cable
236 Source Measure Unit #3
NOTE : Local Sensing Shown

Figure 5-1. Source Measure Unit Substrate Bias Connections

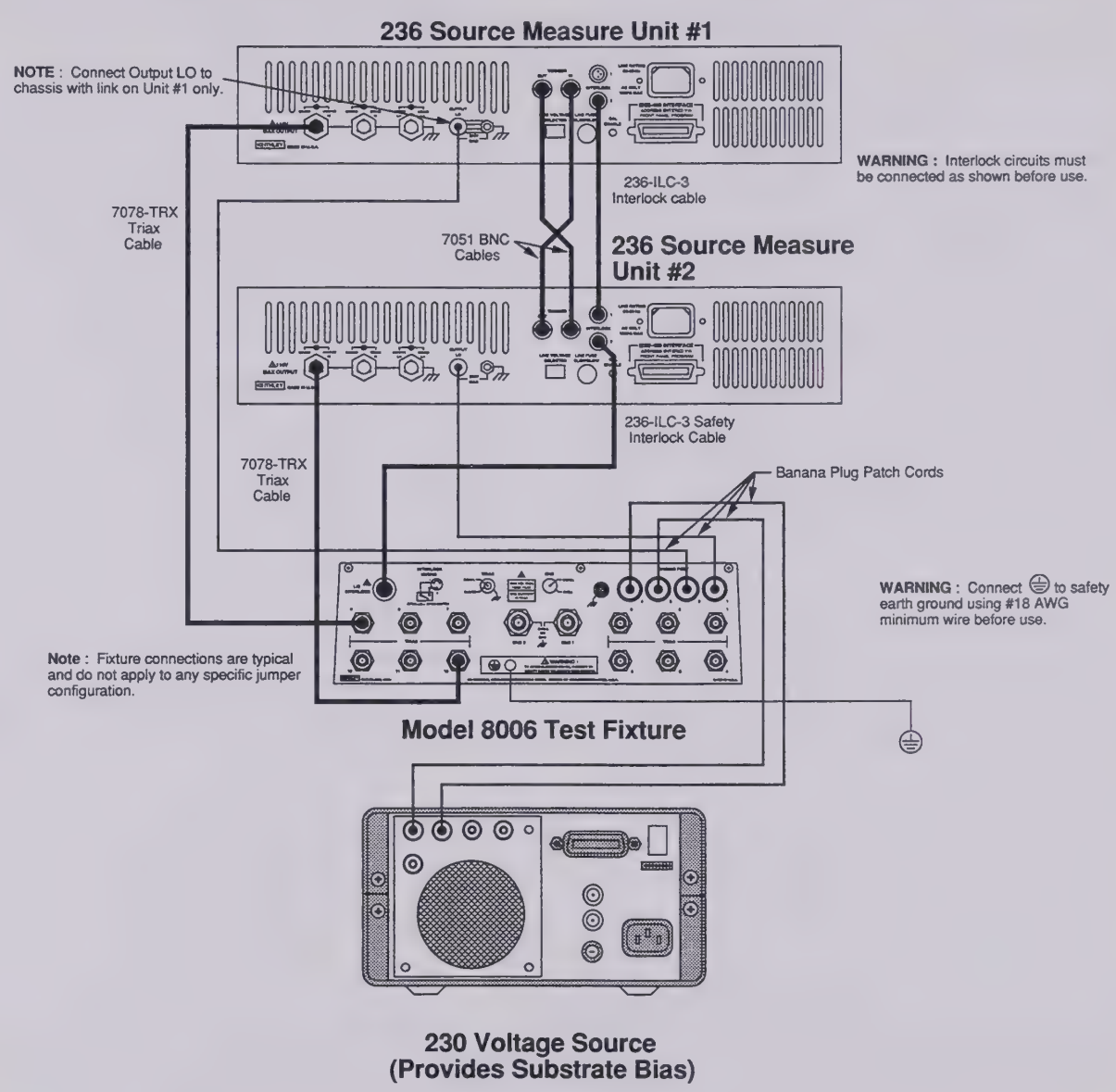

236 Source Measure Unit #1
NOTE : Connect Output LO to chassis with link on Unit #1 only.
WARNING : Interlock circuits must be connected as shown before use.
236-ILC-3 Interlock cable
7078-TRX Triax Cable
7051 BNC Cables
236 Source Measure Unit #2
236-ILC-3 Safety Interlock Cable
7078-TRX Triax Cable
Banana Plug Patch Cords
WARNING : Connect ⏚ to safety earth ground using #18 AWG minimum wire before use.
Note : Fixture connections are typical and do not apply to any specific jumper configuration.
Model 8006 Test Fixture
230 Voltage Source
(Provides Substrate Bias)

Figure 5-2. Voltage Source Substrate Bias Connections

5.4.1 Program 13 Test Configuration

Figure 5-3 shows the test configuration for Program 13 listed below. Unit #1 is used to sweep V_{GS}, while Unit #2 sources V_{DS}. Unit #3 applies a user-defined substrate bias, V_{SB}, to the device under test, and it also measures the substrate current, I_{SB}.

5.4.2 Example Program 13: Substrate Current vs. Gate-source Voltage

Program 13 below demonstrates methods to generate an I_{SB} vs. V_{GS} plot. Follow the steps below to use this program.

1. With the power off, connect all three Source Measure Units to the IEEE-488 bus of the computer.
2. Connect all three units to the test fixture using suitable triax cables. See Figure 5-1 for details on test connections.

NOTE
The external trigger jacks of Unit #1 and Unit #3 must be connected together instead of Unit #1 and Unit #2 as shown. Connect the TRIGGER OUT jack of Unit #1 to the TRIGGER IN jack of Unit #3, and connect the TRIGGER OUT jack of Unit #3 to the TRIGGER IN jack of Unit #1.

3. Turn on all three units, and allow them to warm up for at least two hours for rated accuracy. Verify that the primary address of Unit #1 is set to 16, the primary address of Unit #2 should be set to 17, and the primary address of Unit #3 is set to 18.
4. Turn on the computer, then boot up BASIC.
5. Enter the lines from Program 13 below into the computer.
6. Place a P-channel, enhancement-mode FET with substrate terminal in the appropriate test fixture socket (Keithley part number TG-51). Install the correct jumpers (including substrate bias connections), then close the test fixture lid.
7. RUN the program in the usual fashion. Enter the desired value of substrate bias voltage when prompted to do so. With a P-channel device, the voltage should be positive.
8. The computer will then step through V_{GS} values between 0V and –10V using –1V steps. At each step, the substrate current, I_{SB}, will be measured. After data are collected, a plot of I_{SB} vs. V_{GS} will be generated.
9. To return to BASIC from the graph, press CONT.

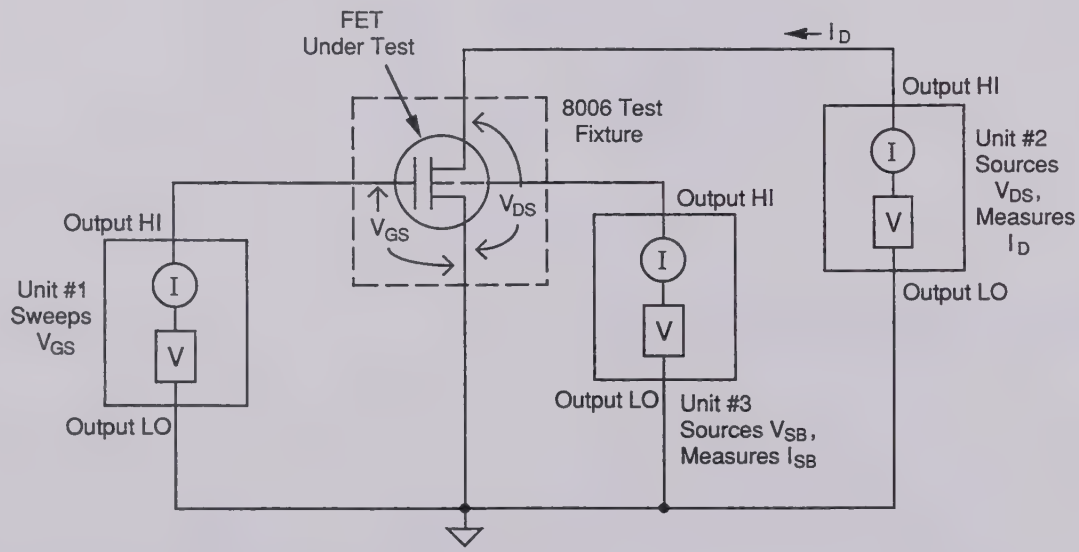


Figure 5-3. Program 13 Test Configuration

5.4.3 Typical Program 13 Results

Figure 5-4 shows a typical plot generated by example Program 13. This plot was made using a Keithley TG-51 MOSFET.

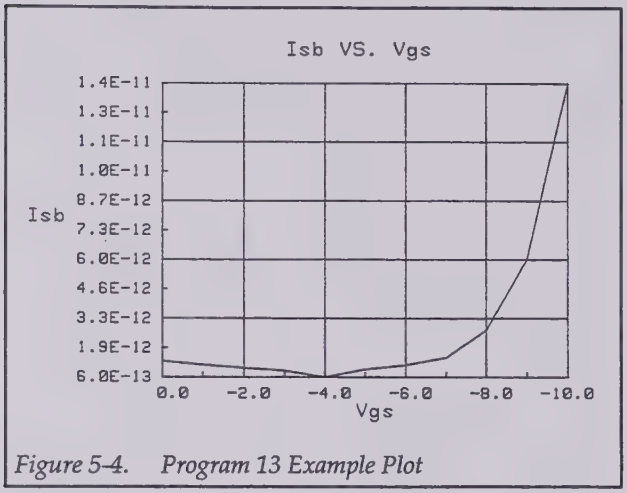


Figure 5-4. Program 13 Example Plot

5.4.4 Program 13 Description

For the description below, refer to the flowchart in Figure 5-5 and the Program 13 listing.

Initially, the reading array is defined for 11 points (line 40). After all three Source Measure Units are returned to default conditions (line 50), Unit #1, which sweeps V_{GS}, is configured as follows (lines 80-180):

- Source V, sweep mode
- 1µA compliance, 1µA range
- Local sense
- External trigger, one trigger per source cycle, output trigger at end of delay
- Source only data format, no prefix, sweep data
- SRQ on sweep done
- Start V_{GS} voltage: 0V
- Stop V_{GS} voltage: –10V
- Step V_{GS} voltage: –1V
- Delay: 10sec
- Staircase sweep

Next, Unit #2, which sources V_{DS}, is set up to operate in the following manner (lines 200-260):

- Source V, dc mode
- Local sensing
- 100mA compliance, 100mA range
- GET trigger, continuous
- Fixed V_{DS} voltage: –10V

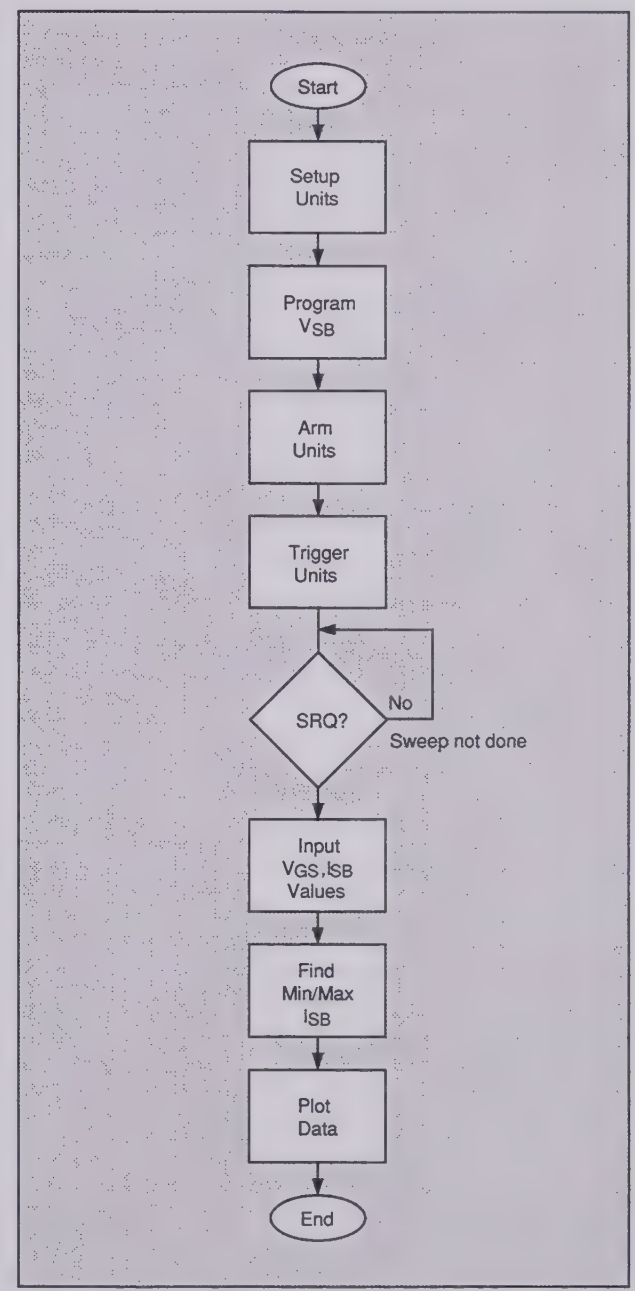


Figure 5-5. Program 13 Flowchart

Finally, Unit #3, which sources V_{SB} and measures I_{SB}, is programmed as follows (lines 280-370):

- Source V, sweep mode
- Local sensing
- 1μA compliance, autorange measure
- External trigger, output trigger at end of each measurement
- Line cycle integration, maximum filtering (32 readings)
- Constant sweep, 11 points, user programmed voltage value

After the operator signal to begin, (lines 380 and 390), all three Source Measure Units are armed and placed into operate (lines 400-420). Unit #2 is then triggered (line 430), and Unit #1 is triggered with the H0X command (line 440) to initiate the sweep.

When Unit #1 is triggered, it sets V_{GS} to the present value in its sweep list. At the end of the programmed delay period, Unit #1 triggers Unit #3 to take a current (I_{SB}) measurement via the external trigger jacks. After Unit #3 measures I_{SB}, it externally triggers Unit #1 to go to the next point in the sweep, and the process repeats.

Meanwhile, the program waits in a loop for Unit #3 to finish its sweep (lines 450 and 460), as indicated by an SRQ. When Unit #3 finishes each sweep, it generates the SRQ, and the program falls out of the loop. The sweep data are then transmitted to the computer (lines 480-510), with V_{GS} placed into array elements (I,1), and I_{SB} values stored in array elements (I,2).

Next, all three units are placed in standby (lines 520-540), and, after operator signal to continue (lines 550-560), the maximum and minimum I_{SB} values are determined (lines 580-630). Finally, the data are plotted (lines 650-940), with I_{SB} along the Y axis, and V_{DS} along the X axis.

5.4.5 Modifying Program 13

For different sweeps, the Vgstart, Vgstop, and Vgstep values can be changes as required. For different sweep lengths, array size and loop counter values must be adjusted accordingly. You can also change the V_{DS} value, if desired, by modifying that parameter accordingly.

```
10    REM SUBSTRATE CURRENT VS. GATE VOLTAGE TEST PROGRAM REV. 1.3 (Program 13)
20    REM SUBSTRATE BIAS AND MEASUREMENT BY SOURCE MEASURE UNIT
30    OPTION BASE 1                    ! First array subscript is 1
40    DIM Reading(11,2)                ! Dimension reading array (11 points)
50    CLEAR 7                          ! Clear instruments
60    OUTPUT KBD;CHR$(255);CHR$(75);   ! Clear screen
70    REM ***** Unit 1 setup (sweeps Vgs) ****************************
80    REMOTE 716                       ! Put Unit 1 in remote
90    OUTPUT 716;"F0,1X"               ! Source V, sweep mode
100   OUTPUT 716;"L1E-6,4X"            ! 1uA compliance, 1uA range
110   OUTPUT 716;"O0X"                 ! Local sense
120   OUTPUT 716;"T3,1,2,0X"           ! External trigger,out trig end of delay
130   OUTPUT 716;"G1,2,1X"             ! Source data,no prefix, sweep data
140   OUTPUT 716;"M2,X"                ! SRQ on sweep done
145   OUTPUT 716;"B0,0,0X"             ! Program 0 bias value
150   Vgstart=0                        ! Define 0V start Vgs voltage
160   Vgstop=-10                       ! Define -10V stop Vgs voltage
170   Vgstep=-1                        ! Define -1V step Vgs voltage
180   Dly=10000                        ! Define 10sec Unit delay
190   OUTPUT 716;"Q1,";Vgstart;",";Vgstop;",";Vgstep;",0,";Dly;"X" ! Pgm swp
200   REM ***** Unit 2 setup (sources Vds) ****************************
210   REMOTE 717                       ! Put Unit 2 in remote
220   OUTPUT 717;"F0,0X"               ! Source V, DC mode
230   OUTPUT 717;"O0X"                 ! Local sensing
240   OUTPUT 717;"L100E-3,9X"          ! 100mA compliance, 100mA range
250   OUTPUT 717;"T1,0,0,0X"           ! Trigger on GET,continuous
260   Vds=-10                          ! Define -10V Vds
270   OUTPUT 717;"B";Vds;",0,0X"       ! Program Vds
280   REM ******** Unit 3 Setup (sources Vsb,measures Isb) ***************
290   REMOTE 718                       ! Put Unit 3 in remote
300   OUTPUT 718;"F0,1X"               ! Source V, sweep mode
310   OUTPUT 718;"O0Z0X"               ! Local sensing,suppress off
320   OUTPUT 718;"L1E-6,0X"            ! 1uA compliance,autorange measure
330   OUTPUT 718;"T3,1,4,0X"           ! Trigger on ext, out trig end of meas
340   OUTPUT 718;"G4,2,1X"             ! Measure data,no prefix,sweep data
350   OUTPUT 718;"S2P5X"               ! Line cycle integration,max filtering
355   OUTPUT 718;"B0,0,0X"             ! Program 0 bias value
360   INPUT "Enter substrate bias (>0)",Vsub! Input desired substrate bias
370   OUTPUT 718;"Q0,";Vsub;",0,";Dly;",11X"  ! Program substrate bias
380   PRINT "Close lid, press CONT to begin test"
390   PAUSE
400   OUTPUT 716;"R1N1X"               ! Arm Unit 1 trigger,turn on output
410   OUTPUT 717;"R1N1X"               ! Arm Unit 2 trigger,turn on output
420   OUTPUT 718;"R1N1X"               ! Arm Unit 3 trigger,turn on output
430   TRIGGER 717                      ! Trigger Unit 2
440   OUTPUT 716;"H0X"                 ! Trigger Unit 1 to start sweep
450   STATUS 7,7;Stat                  ! Get bus status
460   IF NOT BIT(Stat,10) THEN 450     ! Wait for SRQ
470   Stat=SPOLL(716)                  ! Serial poll Unit 1 to clear SRQ
480   FOR I=1 TO 11                    ! Loop for all 11 readings
490   ENTER 716;Reading(I,1)           ! Get Vgs data from Unit 2
500   ENTER 718;Reading(I,2)           ! Get Isb data from Unit 3
```

```
510   NEXT I                          ! Loop back for next Vgs value
520   OUTPUT 716;"N0X"                ! Turn off Unit 1 output
530   OUTPUT 717;"N0X"                ! Turn off Unit 2 output
540   OUTPUT 718;"N0X"                ! Turn off Unit 3 output
550   PRINT "Press CONT to display graph"
560   PRINT "Press CONT while in graph to return to BASIC"
570   PAUSE
580   Ymin=MAXREAL                    ! Find minimum and maximum Isb value
590   Ymax=-MAXREAL
600   FOR I=1 TO 11
610   IF Reading(I,2)<Ymin THEN Ymin=Reading(I,2)
620   IF Reading(I,2)>Ymax THEN Ymax=Reading(I,2)
630   NEXT I
640   OUTPUT KBD;CHR$(255);CHR$(75); ! Clear screen
650   GINIT                           ! Initialize graphics
660   PLOTTER IS CRT,"INTERNAL"       ! Define plot to CRT
670   GRAPHICS ON                     ! Turn on graphics
680   MOVE 55,90                      ! Title graph
690   LABEL "Isb VS. Vgs"
700   MOVE 70,10                      ! Label X axis
710   LABEL "Vgs"
720   MOVE 0,53                       ! Label Y axis
730   LABEL "Isb"
740   VIEWPORT 30,120,20,85           ! Define soft clip limits
750   WINDOW Vgstart,Vgstop,Ymin,Ymax ! Scale graph
760   Y1=(Ymax-Ymin)/10               ! Compute Y axis increment
770   X1=(Vgstop-Vgstart)/10          ! Compute X axis increment
780   GRID 2*X1,2*Y1,Vgstart,Ymin     ! Draw grid
790   AXES X1,Y1,Vgstart,Ymin         ! Add some tick marks
800   PLOT Reading(*)                 ! Plot reading array
810   CSIZE 4                         ! Define character size
820   LORG 6                          ! Center characters
830   CLIP OFF                        ! Turn off soft clipping
840   FOR I=Vgstart TO Vgstop+.01*X1 STEP 2*X1 ! Number X axis
850   MOVE I,Ymin-(Y1/4)
860   LABEL USING "#,MDD.D";I
870   NEXT I
880   FOR I=Ymin TO Ymax+.01*Y1 STEP Y1 ! Number Y axis
890   MOVE Vgstart-(1.3*X1),I+(.3*Y1)
900   LABEL USING "#,MD.DE";I
910   NEXT I
920   PAUSE
930   OUTPUT KBD;CHR$(255);CHR$(75); ! Clear alpha screen
940   GRAPHICS OFF                    ! Clear graphics screen
950   END
```

5.4.6 Program 14 Test Configuration

Figure 5-6 shows the test configuration for Program 14 listed below. Unit #1 is used to sweep V_{GS}, while Unit #2 sweeps V_{DS} and measures I_D. Unit #3 applies a user-defined substrate bias to the device under test. Common source characteristics are generated by data taken when the program is run.

5.4.7 Example Program 14: Common-source Characteristics with Source Measure Unit Substrate Bias

Program 14 below demonstrates common-source characteristic test programming with substrate bias. Follow the steps below to use this program.

1. With the power off, connect all three Source Measure Units to the IEEE-488 bus of the computer.
2. Connect all three units to the test fixture using suitable triax cables (see Figure 5-1 for details on test connections).
3. Turn on all three units, and allow them to warm up for at least two hours for rated accuracy. Verify that the primary address of Unit #1 is set to 16, the primary address of Unit #2 is at 17, and the primary address of Unit #3 is set to 18.
4. Turn on the computer, then boot up BASIC.
5. Enter the lines from Program 14 below into the computer.
6. Place a packaged device containing N-channel, depletion-mode FETs in the appropriate test fixture socket (the devices should have characteristics similar to the 2N4392 JFET used for other examples in this section). Install the correct jumpers (including substrate bias connections), then close the test fixture lid.
7. RUN the program in the usual fashion. Enter the desired value of substrate bias when prompted to do so.
8. The unit will then step through V_{GS} values between –2V and 0V using 0.5V steps. At each step, V_{DS} will be stepped between 0V and 10V at 0.1V increments. At each increment, I_D will be measured. Once data are collected, a plot of I_D vs. V_{DS} for each V_{GS} value will be displayed.
9. To return to BASIC from the graph, press CONT.

5.4.8 Typical Program 14 Results

Figure 5-7 shows a typical plot generated by example Program 14.

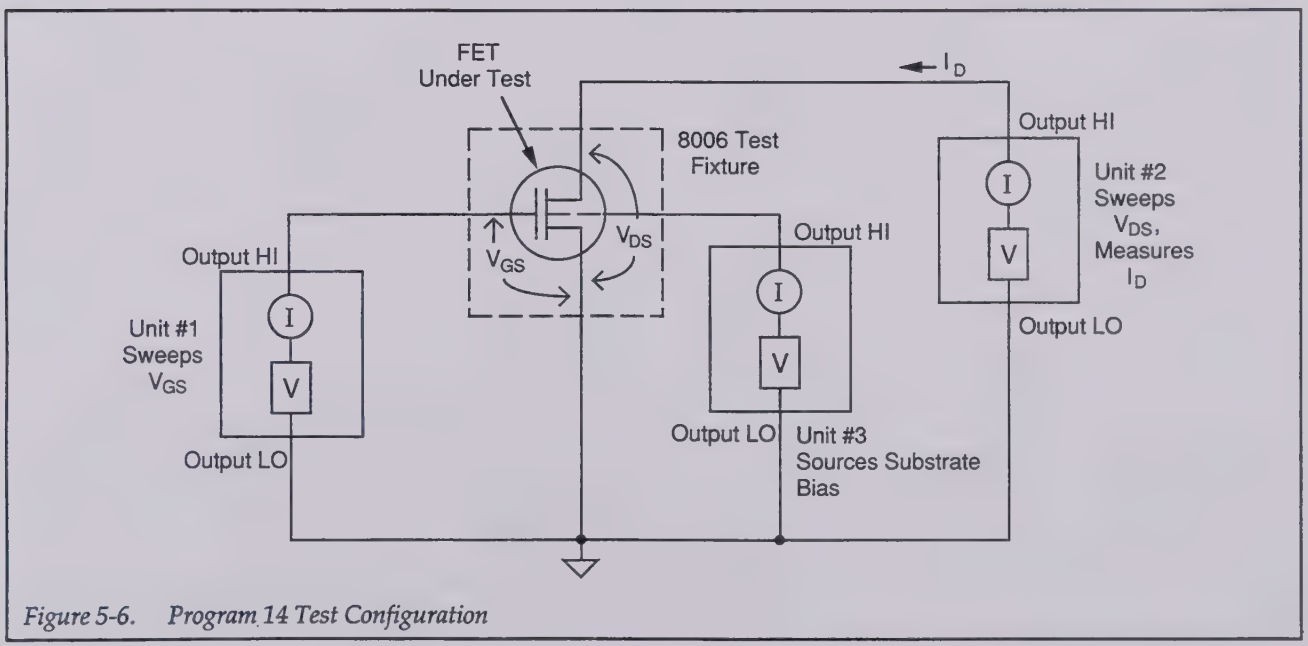


Figure 5-6. Program 14 Test Configuration

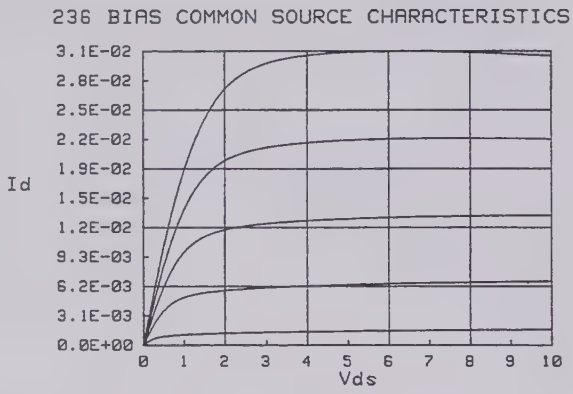


Figure 5-7. Program 14 Example Plot

5.4.9 Program 14 Description

For the description below, refer to the flowchart in Figure 5-8 and the Program 14 listing.

Initially, the reading array is defined for five sweeps with 101 points each (lines 30 and 40). After all three Source Measure Units are returned to default conditions (line 50), Unit #1, which sweeps V_{GS}, is configured as follows (lines 80-170):

- Source V, sweep mode
- 1mA compliance, 1mA range
- Local sense
- Get trigger, one trigger per source cycle, output trigger at end of delay
- Start V_{GS} voltage: –2V
- Stop V_{GS} voltage: 0V
- Step V_{GS} voltage: 0.5V
- Delay: 100msec
- Staircase sweep

Next, Unit #2, which sweeps V_{DS} and measures I_D, is set up to operate in the following manner (lines 200-310):

- Source V, sweep mode
- Local sensing
- 100mA compliance, autorange measure
- Source and measure data format, no prefix, sweep data
- SRQ on sweep done
- External trigger, continuous
- Line cycle integration
- Suppress enabled
- Start V_{DS} voltage: 0V
- Stop V_{DS} voltage: 10V
- Step V_{DS} voltage: 0.1V
- Delay: 100msec
- Staircase sweep

Finally, Unit #3, which provides substrate bias, is programmed as follows (lines 330-390):

- Source V, dc mode
- Local sensing
- 10mA compliance, autorange measure
- Trigger on GET, continuous
- Dc output, voltage determined by user input

After the operator signal to begin, (lines 400 and 410), all three Source Measure Units are armed and placed into operate (lines 420-440). Unit #3 is then triggered (line 450), and the program enters the main program loop to perform five I_D vs. V_{DS} sweeps, one for each of five V_{GS} values (line 460).

Unit #1 is GET triggered to initiate each sweep, at which point it sets V_{GS} to the present value in its sweep list. At the end of the programmed delay period, Unit #1 triggers Unit #2 to begin its sweep via the external trigger jacks. Unit #2 then cycles through its sweep list, setting V_{DS} to the required values, and measuring I_D at each step along the way.

Meanwhile, the program waits in a loop for Unit #2 to finish its sweep (lines 490 and 500), as indicated by an SRQ. When Unit #2 finishes each sweep, it generates the SRQ, and the program falls through the loop. The sweep data are then transmitted to the computer (lines 520-540), with V_{DS} placed into array elements (I,J,1), and I_D values stored in array elements (I,J,2). The program then loops back for the next sweep until all five sweeps have been performed (line 550).

Next, all three units are placed in standby (lines 560-580), and, after operator signal to continue (lines 570-580), the maximum and minimum I_D values are determined (lines 620-690). Finally, the data are plotted (lines 710-1050), with I_D along the Y axis, and V_{DS} along the X axis.

5.4.10 Modifying Program 14

For different sweeps, the Vgstart, Vgstop, Vgstep, Vdstart, Vdstop, and Vdstep values can be changed as required. For different sweep lengths, array size and loop counter values must be adjusted accordingly.

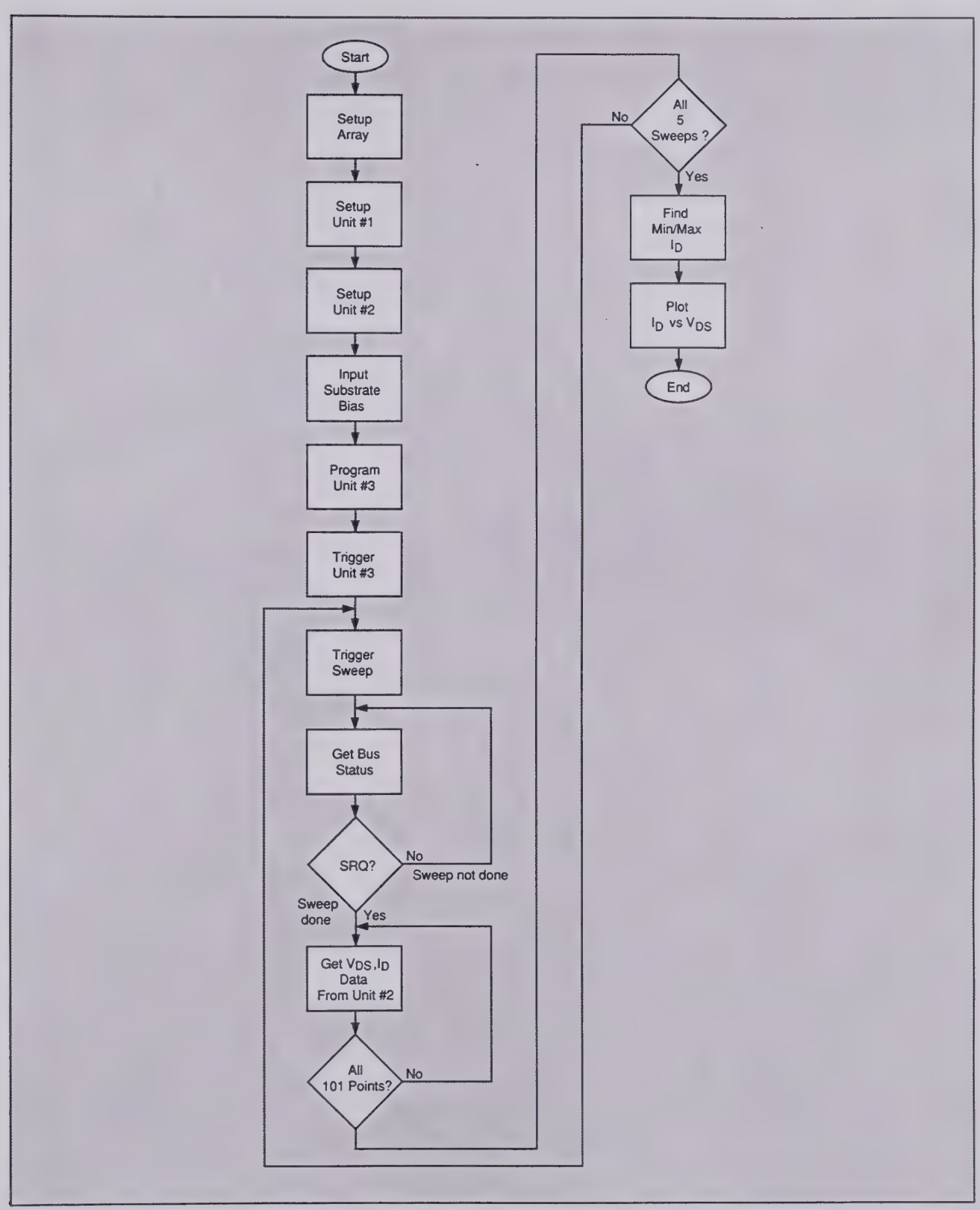


Figure 5-8. Program 14 Flowchart

```
10    REM COMMON SOURCE CHARACTERISTIC TEST PROGRAM REV. 1.3 (Program 14)
20    REM INCLUDES SUBSTRATE BIAS PROGRAMMING FOR Unit 3
30    OPTION BASE 1                    ! First array subscript is 1
40    DIM Reading(5,101,2)             ! Dimension reading array (5 swps,100 pts)
50    CLEAR 7                          ! Clear instruments
60    OUTPUT KBD;CHR$(255);CHR$(75);   ! Clear screen
70    REM ***** Unit 1 setup (sweeps Vgs) ****************************
80    REMOTE 716                       ! Put Unit 1 in remote
90    OUTPUT 716;"F0,1X"               ! Source V, sweep mode
100   OUTPUT 716;"L1E-3,7X"            ! 1mA compliance, 1mA range
110   OUTPUT 716;"O0X"                 ! Local sense
120   OUTPUT 716;"T1,1,2,0X"           ! GET trigger cycle,out trig end of delay
125   OUTPUT 716;"B0,0,0X"             ! Program 0 bias value
130   Vgstart=-2                       ! Define -2V start Vgs voltage
140   Vgstop=0                         ! Define 0V stop Vgs voltage
150   Vgstep=.5                        ! Define 0.5V step Vgs voltage
160   Dly=100                          ! Define 100msec Unit delay
170   OUTPUT 716;"Q1,";Vgstart;",";Vgstop;",";Vgstep;",0,";Dly;"X" ! Pgm swp
180   REM ***** Unit 2 setup (sweeps Vds, measures Id) ***************
190   REMOTE 717                       ! Put Unit 2 in remote
200   OUTPUT 717;"F0,1X"               ! Source V, sweep mode
210   OUTPUT 717;"O0X"                 ! Local sensing
220   OUTPUT 717;"L100E-3,0X"          ! 100mA compliance,autorange measure
230   OUTPUT 717;"G5,2,1X"             ! Source,measure,no prefix,sweep data
240   OUTPUT 717;"M2,X"                ! SRQ on sweep done
250   OUTPUT 717;"T3,0,0,0X"           ! Trigger on external,continuous
260   OUTPUT 717;"S2X"                 ! Line cycle integration
265   OUTPUT 717;"B0,0,0X"             ! Program 0 bias value
270   OUTPUT 717;"Z1X"                 ! Enable suppress
280   Vdstart=0                        ! Define 0V start Vds
290   Vdstop=10                        ! Define 10V stop Vds
300   Vdstep=.1                        ! Define 0.1V step Vds
310   OUTPUT 717;"Q1,";Vdstart;",";Vdstop;",";Vdstep;",0,";Dly;"X" ! Pgm swp
320   REM ******** Unit 3 Setup (provides substrate bias) ***************
330   REMOTE 718                       ! Put Unit 3 in remote
340   OUTPUT 718;"F0,0X"               ! Source V, DC mode
350   OUTPUT 718;"O0X"                 ! Local sensing
360   OUTPUT 718;"L1E-3,7X"            ! 1mA compliance, 1mA range
370   OUTPUT 718;"T1,0,0,0X"           ! Trigger on GET, continuous
380   INPUT "Enter substrate bias",Vsub! Input desired substrate bias voltage
390   OUTPUT 718;"B";Vsub;",0,0X"      ! Program substrate bias
400   PRINT "Close lid, press CONT to begin test"
410   PAUSE
420   OUTPUT 716;"R1N1X"               ! Arm Unit 1 trigger,turn on output
430   OUTPUT 717;"R1N1X"               ! Arm Unit 2 trigger, turn on output
440   OUTPUT 718;"R1N1X"               ! Arm Unit 3 trigger, turn on output
450   TRIGGER 718                      ! Trigger Unit 3
460   FOR I=1 TO 5                     ! Loop for five Vgs curves
470   PRINT "Generating sweep";I
480   TRIGGER 716                      ! Trigger Unit 1 to start sweep
490   STATUS 7,7;Stat                  ! Get IEEE-488 bus status
500   IF NOT BIT(Stat,10) THEN 490     ! Wait for Unit 2 SRQ on sweep done
```

```
510   Stat=SPOLL(717)                  ! Serial poll Unit 2 to clear SRQ
520   FOR J=1 TO 101                   ! Loop for all 101 readings
530   ENTER 717;Reading(I,J,1),Reading(I,J,2) ! Get reading data from Unit 2
540   NEXT J                           ! Loop back for next reading
550   NEXT I                           ! Loop back for next Vgs value
560   OUTPUT 716;"N0X"                 ! Turn off Unit 1 output
570   OUTPUT 717;"N0X"                 ! Turn off Unit 2 output
580   OUTPUT 718;"N0X"                 ! Turn off Unit 3 output
590   PRINT "Press CONT to display graph"
600   PRINT "Press CONT while in graph to return to BASIC"
610   PAUSE
620   Ymin=MAXREAL                     ! Find minimum and maximum Id value
630   Ymax=-MAXREAL
640   FOR I=1 TO 5
650   FOR J=1 TO 101
660   IF Reading(I,J,2)<Ymin THEN Ymin=Reading(I,J,2)
670   IF Reading(I,J,2)>Ymax THEN Ymax=Reading(I,J,2)
680   NEXT J
690   NEXT I
700   OUTPUT KBD;CHR$(255);CHR$(75); ! Clear screen
710   GINIT                            ! Initialize graphics
720   PLOTTER IS CRT,"INTERNAL"        ! Define plot to CRT
730   GRAPHICS ON                      ! Turn on graphics
740   MOVE 10,90                       ! Title graph
750   LABEL "236 BIAS COMMON SOURCE CHARACTERISTICS"
760   MOVE 70,10                       ! Label X axis
770   LABEL "Vds"
780   MOVE 0,53                        ! Label Y axis
790   LABEL "Id"
800   VIEWPORT 30,120,20,85            ! Define soft clip limits
810   WINDOW Vdstart,Vdstop,Ymin,Ymax ! Scale graph
820   Y1=(Ymax-Ymin)/10                ! Compute Y axis increment
830   X1=(Vdstop-Vdstart)/10           ! Compute X axis increment
840   GRID 2*X1,2*Y1,Vdstart,Ymin      ! Draw grid
850   AXES X1,Y1,Vdstart,Ymin          ! Add some tick marks
860   FOR I=1 TO 5                     ! Loop for all five curves
870   FOR J=1 TO 101                   ! Loop for all 101 points per curve
880   PLOT Reading(I,J,1),Reading(I,J,2) ! Plot point
890   NEXT J                           ! Plot next point
900   PENUP
910   NEXT I                           ! Plot next curve
920   CSIZE 4                          ! Define character size
930   LORG 6                           ! Center characters
940   CLIP OFF                         ! Turn off soft clipping
950   FOR I=Vdstart TO Vdstop+.01*X1 STEP X1 ! Number X axis
960   MOVE I,Ymin-(Y1/4)
970   LABEL USING "#,K";I
980   NEXT I
990   FOR I=Ymin TO Ymax+.01*Y1 STEP Y1 ! Number Y axis
1000  MOVE Vdstart-(1.3*X1),I+(.3*Y1)
```

```
1010  LABEL USING "#,MD.DE";I
1020  NEXT I
1030  PAUSE
1040  OUTPUT KBD;CHR$(255);CHR$(75); ! Clear alpha screen
1050  GRAPHICS OFF                   ! Clear graphics screen
1060  END
```

5.5 VOLTAGE SOURCE SUBSTRATE BIASING

The following paragraphs discuss using a Model 230 Programmable Voltage Source to bias the substrate. Once again, the example programs included in this paragraph are modified versions of the common-source and common-emitter characteristic test programs presented earlier in this manual.

5.5.1 Program 15 Test Configuration

Figure 5-9 shows the test configuration for Program 15 listed below. Unit #1 is used to sweep V_{GS}. Unit #2 sweeps V_{DS}, and the instrument also measures I_D. The Model 230 Voltage Source applies a substrate bias (defined by the user) to the device under test.

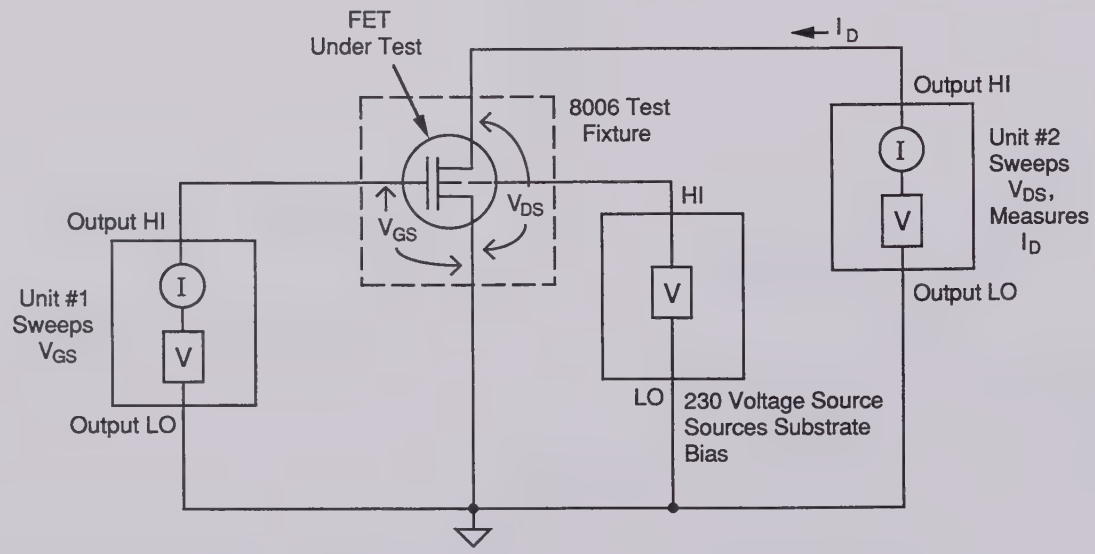


Figure 5-9. Program 15 Test Configuration

5.5.2 Example Program 15: Common-source Characteristics with Voltage Source Substrate Bias

Program 15 below demonstrates common-source characteristic test programming with substrate bias applied by a separate voltage source. Proceed as outlined below.

1. With the power off, connect both Source Measure Units and the voltage source to the IEEE-488 bus of the computer.
2. Connect both units to the test fixture using suitable triax cables. Also, connect the voltage source output to the binding posts (or use BNC connections for shielding). See Figure 5-2 for details on test connections.
3. Turn on all three instruments, and allow them to warm up for at least two hours for rated accuracy. Verify that the primary address of Unit #1 is set to 16, the primary address of Unit #2 is set to 17, and that the primary address of the voltage source is set to 13.
4. Turn on the computer, then boot up BASIC.
5. Enter the lines from Program 15 below into the computer.
6. Place a device containing an N-channel, depletion-mode FET in the appropriate test fixture socket (FET characteristics should be similar to those of the 2N4392 JFET used for other examples in this section). Install the correct jumpers (including substrate bias connections), then close the test fixture lid.
7. RUN the program in the usual fashion. Enter the desired value of substrate bias when prompted to do so.
8. The computer will then step through V_{GS} values between –2V and 0V using 0.5V steps. At each step, V_{DS} will be stepped between 0V and 10V at 0.1V increments. At each increment, I_D will be measured. Once data are collected, a plot of I_D vs. V_{DS} for each V_{GS} value will be displayed.
9. To return to BASIC from the graph, press CONT.

5.5.3 Typical Program 15 Results

A typical plot generated by Program 15 is shown in Figure 5-10.

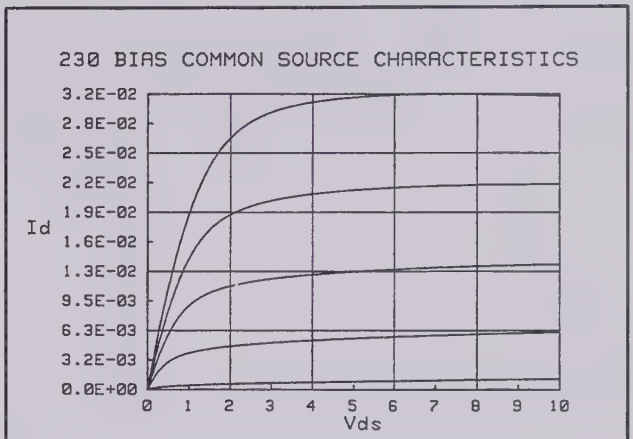


Figure 5-10. Program 15 Example Plot

5.5.4 Program 15 Description

For the description below, refer to the flowchart in Figure 5-11 and the Program 15 listing also shown below.

First, the reading array is defined for five sweeps with 101 points each (lines 30 and 40). After all three instruments are returned to default conditions (line 50), Unit #1, which sweeps V_{GS}, is configured as follows (lines 80-170):

- Source V, sweep mode
- 1mA compliance, 1mA range
- Local sense
- Get trigger, one trigger per source cycle, output trigger at end of delay
- Start V_{GS} voltage: –2V
- Stop V_{GS} voltage: 0V
- Step V_{GS} voltage: 0.5V
- Delay: 100msec
- Staircase sweep

Next, Unit #2, which sweeps V_{DS} and measures I_D, is set up to operate in the following manner (lines 190-310):

- Source V, sweep mode
- Local sensing
- 100mA compliance, autorange measure
- Source and measure data format, no prefix, sweep data
- SRQ on sweep done
- External trigger, continuous
- Line cycle integration
- Suppress enabled
- Start V_{DS} voltage: 0V
- Stop V_{DS} voltage: 10V
- Step V_{DS} voltage: 0.1V
- Delay: 100msec
- Staircase sweep

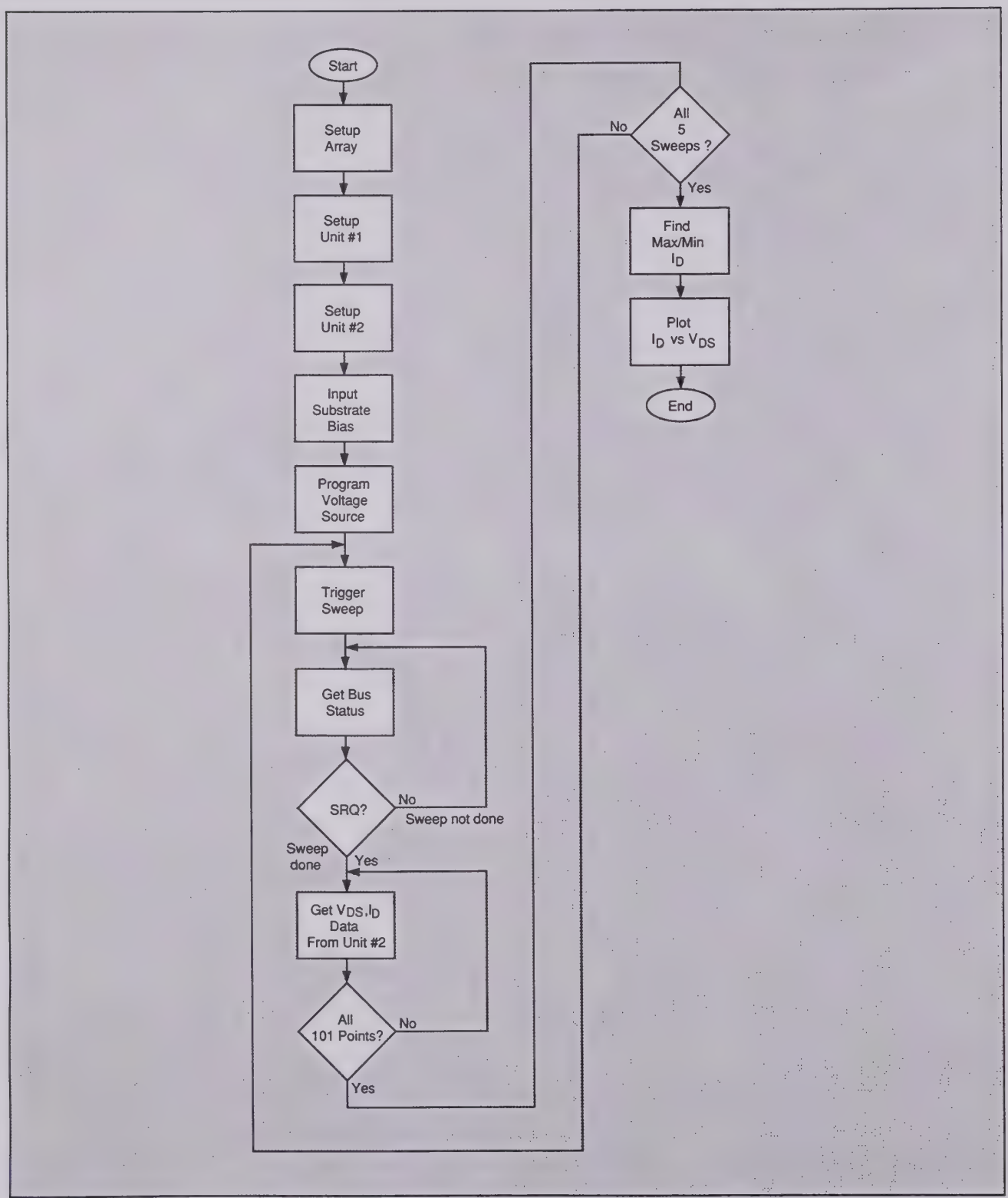


Figure 5-11. Program 15 Flowchart

Finally, the Model 230 Voltage Source, which provides substrate bias, is programmed with the user-input substrate bias voltage (lines 330-350).

After the operator signal to begin, (lines 360 and 370), both Source Measure Units are armed and placed into operate (lines 380 and 390). The voltage source output is turned on (line 400), and the program enters the main program loop to perform five I_D vs. V_{DS} sweeps, one for each of five V_{GS} values (line 410).

Unit #1 is GET triggered to initiate each sweep, at which point it sets V_{GS} to the present value in its sweep list. At the end of the programmed delay period, Unit #1 triggers Unit #2 to begin its sweep via the external trigger jacks. Unit #2 then cycles through its sweep list, setting V_{DS} to the required values, and measuring I_D at each step along the way.

At the same time, the program waits in a loop for Unit #2 to finish its sweep (lines 440 and 450), as indicated by an SRQ. When Unit #2 finishes each sweep, it generates the SRQ, and the program falls through the loop. The sweep data are then transmitted to the computer (lines 470-490), with V_{DS} placed into array elements (I,J,1), and I_D values stored in array elements (I,J,2). The program then loops back for the next sweep until all five sweeps have been performed (line 500).

Next, both units and the voltage source are placed in standby (lines 510-530), and, after operator signal to continue (lines 540 and 550), the maximum and minimum I_D values are determined (lines 70-640). Finally, the data are plotted (lines 660-1000), with I_D along the Y axis, and V_{DS} along the X axis.

5.5.5 Modifying Program 15

For different sweeps, the Vgstart, Vgstop, Vgstep, Vdstart, Vdstop, and Vdstep values can be changed as required. For different sweep lengths, array size and loop counter values must be adjusted accordingly.

```
10    REM COMMON SOURCE CHARACTERISTIC TEST PROGRAM REV. 1.3 (Program 15)
20    REM INCLUDES SUBSTRATE BIAS PROGRAMMING FOR 230 VOLTAGE SOURCE
30    OPTION BASE 1                    ! First array subscript is 1
40    DIM Reading(5,101,2)             ! Dimension reading array (5 swps,101 pts)
50    CLEAR 7                          ! Clear instruments
60    OUTPUT KBD;CHR$(255);CHR$(75);   ! Clear screen
70    REM ***** Unit 1 setup (sweeps Vgs) ****************************
80    REMOTE 716                       ! Put Unit 1 in remote
90    OUTPUT 716;"F0,1X"               ! Source V, sweep mode
100   OUTPUT 716;"L1E-3,7X"            ! 1mA compliance, 1mA range
110   OUTPUT 716;"O0X"                 ! Local sense
120   OUTPUT 716;"T1,1,2,0X"           ! GET trigger cycle,out trig end of delay
125   OUTPUT 716;"B0,0,0X"             ! Program 0 bias value
130   Vgstart=-2                       ! Define -2V start Vgs voltage
140   Vgstop=0                         ! Define 0V stop Vgs voltage
150   Vgstep=.5                        ! Define 0.5V step Vgs voltage
160   Dly=100                          ! Define 100msec Unit delay
170   OUTPUT 716;"Q1,";Vgstart;",";Vgstop;",";Vgstep;",0,";Dly;"X" ! Pgm swp
180   REM ***** Unit 2 setup (sweeps Vgs, measures Id) ***************
190   REMOTE 717                       ! Put Unit 2 in remote
200   OUTPUT 717;"F0,1X"               ! Source V, sweep mode
210   OUTPUT 717;"O0X"                 ! Local sensing
220   OUTPUT 717;"L100E-3,0X"          ! 100mA compliance,autorange measure
230   OUTPUT 717;"G5,2,1X"             ! Source,measure,no prefix,sweep data
240   OUTPUT 717;"M2,X"                ! SRQ on sweep done
250   OUTPUT 717;"T3,0,0,0X"           ! Trigger on external,continuous
260   OUTPUT 717;"S2X"                 ! Line cycle integration
265   OUTPUT 717;"B0,0,0X"             ! Program 0 bias value
270   OUTPUT 717;"Z1X"                 ! Enable suppress
280   Vdstart=0                        ! Define 0V start Vds
290   Vdstop=10                        ! Define 10V stop Vds
300   Vdstep=.1                        ! Define 0.1V step Vds
310   OUTPUT 717;"Q1,";Vdstart;",";Vdstop;",";Vdstep;",0,";Dly;"X" ! Pgm swp
320   REM ******** 230 voltage source setup (provides substrate bias) ********
330   REMOTE 713                       ! Put 230 in remote
340   INPUT "Enter substrate bias",Vsub! Input desired substrate bias voltage
350   OUTPUT 713;"V";Vsub;"X"          ! Program substrate bias
360   PRINT "Close lid, press CONT to begin test"
370   PAUSE
380   OUTPUT 716;"R1N1X"               ! Arm Unit 1 trigger, turn on output
390   OUTPUT 717;"R1N1X"               ! Arm Unit 2 trigger, turn on output
400   OUTPUT 713;"F1X"                 ! Turn on 230 output
410   FOR I=1 TO 5                     ! Loop for five Vgs curves
420   PRINT "Generating sweep";I
430   TRIGGER 716                      ! Trigger Unit 1 to start sweep
440   STATUS 7,7;Stat                  ! Get IEEE-488 bus status
450   IF NOT BIT(Stat,10) THEN 440     ! Wait for Unit 2 SRQ on sweep done
460   Stat=SPOLL(717)                  ! Serial poll Unit 2 to clear SRQ
470   FOR J=1 TO 101                   ! Loop for all 101 readings
480   ENTER 717;Reading(I,J,1),Reading(I,J,2) ! Get reading data from Unit 2
490   NEXT J                           ! Loop back for next reading
500   NEXT I                           ! Loop back for next Vgs value
510   OUTPUT 716;"N0X"                 ! Turn off Unit 1 output
```

```
520   OUTPUT 717;"N0X"                ! Turn off Unit 2 output
530   OUTPUT 713;"F0X"                ! Turn off 230 output
540   PRINT "Press CONT to display graph"
550   PRINT "Press CONT while in graph to return to BASIC"
560   PAUSE
570   Ymin=MAXREAL                    ! Find minimum and maximum Id value
580   Ymax=-MAXREAL
590   FOR I=1 TO 5
600   FOR J=1 TO 101
610   IF Reading(I,J,2)<Ymin THEN Ymin=Reading(I,J,2)
620   IF Reading(I,J,2)>Ymax THEN Ymax=Reading(I,J,2)
630   NEXT J
640   NEXT I
650   OUTPUT KBD;CHR$(255);CHR$(75); ! Clear screen
660   GINIT                           ! Initialize graphics
670   PLOTTER IS CRT,"INTERNAL"       ! Define plot to CRT
680   GRAPHICS ON                     ! Turn on graphics
690   MOVE 10,90                      ! Title graph
700   LABEL "230 BIAS COMMON SOURCE CHARACTERISTICS"
710   MOVE 70,10                      ! Label X axis
720   LABEL "Vds"
730   MOVE 0,53                       ! Label Y axis
740   LABEL "Id"
750   VIEWPORT 30,120,20,85           ! Define soft clip limits
760   WINDOW Vdstart,Vdstop,Ymin,Ymax ! Scale graph
770   Y1=(Ymax-Ymin)/10               ! Compute Y axis increment
780   X1=(Vdstop-Vdstart)/10          ! Compute X axis increment
790   GRID 2*X1,2*Y1,Vdstart,Ymin     ! Draw grid
800   AXES X1,Y1,Vdstart,Ymin         ! Add some tick marks
810   FOR I=1 TO 5                    ! Loop for all five curves
820   FOR J=1 TO 101                  ! Loop for all 101 points per curve
830   PLOT Reading(I,J,1),Reading(I,J,2) ! Plot point
840   NEXT J                          ! Plot next point
850   PENUP
860   NEXT I                          ! Plot next curve
870   CSIZE 4                         ! Define character size
880   LORG 6                          ! Center characters
890   CLIP OFF                        ! Turn off soft clipping
900   FOR I=Vdstart TO Vdstop+.01*X1 STEP X1! Number X axis
910   MOVE I,Ymin-(Y1/4)
920   LABEL USING "#,K";I
930   NEXT I
940   FOR I=Ymin TO Ymax+.01*Y1 STEP Y1 ! Number Y axis
950   MOVE Vdstart-(1.3*X1),I+(.3*Y1)
960   LABEL USING "#,MD.DE";I
970   NEXT I
980   PAUSE
990   OUTPUT KBD;CHR$(255);CHR$(75); ! Clear alpha screen
1000  GRAPHICS OFF                    ! Clear graphics screen
1010  END
```

5.5.6 Program 16 Test Configuration

Figure 5-12 shows the test configuration for Program 16 listed below. Unit #1 is used to sweep I_B, while Unit #2 sweeps V_{CE} and measures I_C. The voltage source applies a user-programmed substrate bias to the device under test.

5.5.7 Example Program 16: Common-emitter Characteristics with Voltage Source Substrate Bias

Program 16 below demonstrates common-emitter characteristic test programming with substrate bias. Proceed as follows:

1. With the power off, connect both Source Measure Units and the voltage source to the IEEE-488 bus of the computer.
2. Connect both units to the test fixture using suitable triax cables, and connect the voltage source to the binding posts using patch cords (or use coax cable and BNC connections for shielding). See Figure 5-2 for details on test connections.
3. Turn on all three instruments, and allow them to warm up for at least two hours for rated accuracy. Verify that the primary address of Unit #1 is set to 16, the primary address of Unit #2 is set to 17, and the primary address of the Model 230 Voltage Source is set to 13.
4. Turn on the computer, then boot up BASIC.
5. Enter the lines from Program 16 below into the computer.
6. Place a device containing an NPN bipolar transistor in the appropriate test fixture socket (the device should have characteristics similar to a 2N3904 or 2N5089, which are used for other examples in this section). Install the correct jumpers (including substrate bias connections), then close the test fixture lid.
7. RUN the program in the usual fashion. Enter the desired value of substrate bias when prompted to do so.
8. The computer will then step through I_B values between 10µA and 50µA using 10µA steps. At each step, V_{CE} will be stepped between 0V and 10V at 0.1V increments. At each increment, I_C will be measured. Once data are collected, a plot of I_C vs. V_{CE} for each I_B value will be displayed.
9. To return to BASIC from the graph, press CONT.

5.5.8 Typical Program 16 Results

Figure 5-13 shows a typical plot generated by example Program 16.

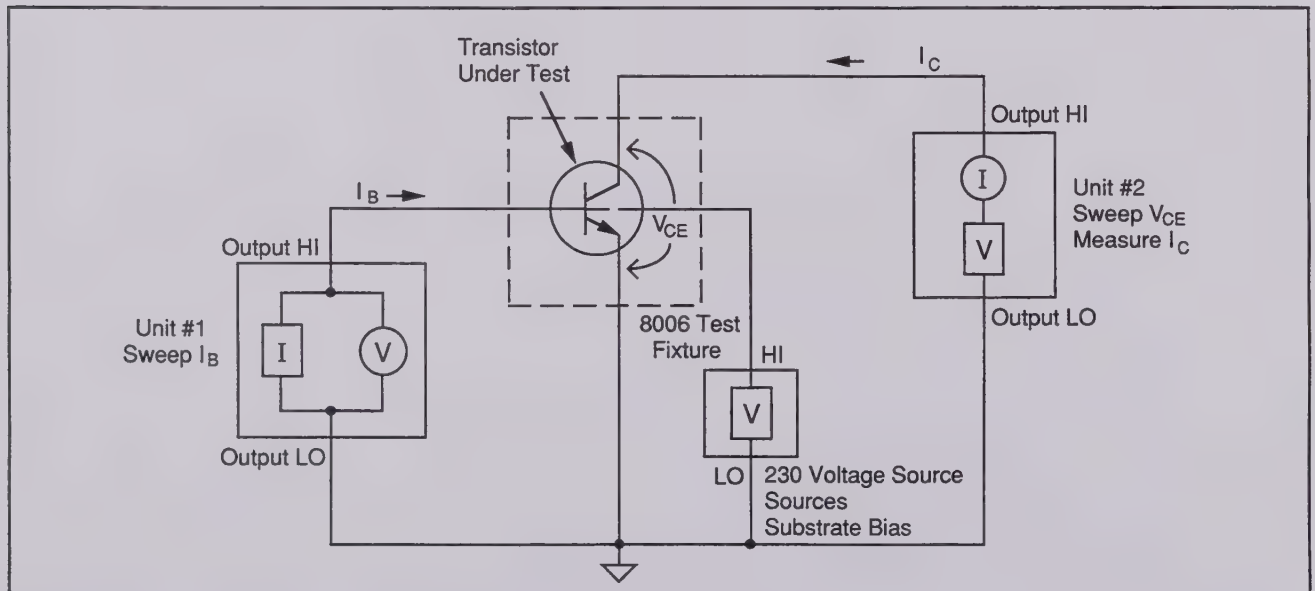


Figure 5-12. Program 16 Test Configuration

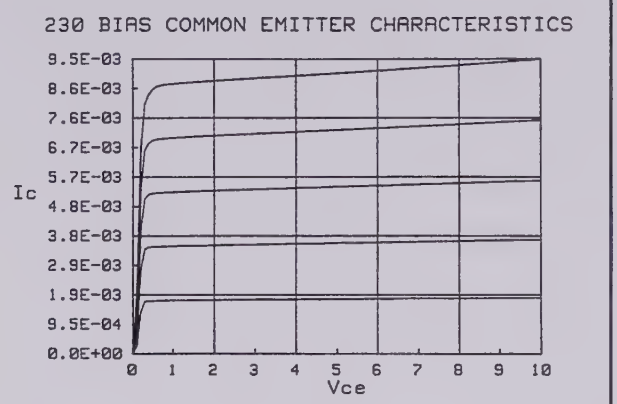


Figure 5-13. Example Plot Generated by Program 16

5.5.9 Program 16 Description

For the description below, refer to the flowchart in Figure 5-14 as well as the Program 16 listing below.

Initially, the reading array is defined for five sweeps with 101 points each (lines 30 and 40). After all three instruments are returned to default conditions (line 50), Unit #1, which sweeps I_B, is configured as follows (lines 80-170):

- Source I, sweep mode
- 1V compliance, 1.1V range
- Local sense
- Get trigger, one trigger per source cycle, output trigger at end of delay
- Start I_B current: 10µA
- Stop I_B current: 50µA
- Step I_B current: 10µA
- Delay: 100msec
- Staircase sweep

Next, Unit #2, which sweeps V_{CE} and measures I_C, is set up to operate in the following manner (lines 190-310):

- Source V, sweep mode
- Local sensing
- 100mA compliance, autorange measure
- Source and measure data format, no prefix, sweep data
- SRQ on sweep done
- External trigger, continuous
- Line cycle integration
- Suppress enabled
- Start V_{CE} voltage: 0V
- Stop V_{CE} voltage: 10V
- Step V_{CE} voltage: 0.1V
- Delay: 100msec
- Staircase sweep

Finally, the voltage source, which provides substrate bias, is programmed with the user-input voltage value (lines 320-350).

After the operator signal to begin, (lines 360 and 370), both Source Measure Units are armed and placed into operate (lines 380 and 390). The voltage source is placed into operate (line 400), and the program enters the main program loop to perform five I_C vs. V_{CE} sweeps, one for each of five I_B values (line 410).

Unit #1 is GET triggered to initiate each sweep (line 430), at which point it sets I_B to the present value in its sweep list. At the end of the programmed delay period, Unit #1 triggers Unit #2 to begin its sweep via the external trigger jacks. Unit #2 then cycles through its sweep list, setting V_{CE} to the required values, and measuring I_C at each step along the way.

At the same time, the program waits in a loop for Unit #2 to finish its sweep (lines 440 and 450), as indicated by an SRQ. When Unit #2 finishes each sweep, it generates the SRQ, and the program falls through the loop. The sweep data are then transmitted to the computer (lines 470-490), with V_{CE} values placed into array elements (I,J,1), and I_C values stored in array elements (I,J,2). The program then loops back for the next sweep until all five sweeps have been performed (line 500).

Next, both units and the voltage source are placed in standby (lines 510-530), and, after operator signal to continue (lines 540-560), the maximum and minimum I_C values are determined (lines 570-640). Finally, the data are plotted (lines 660-1000), with I_C along the Y axis, and V_{CE} along the X axis.

5.5.10 Modifying Program 16

For different sweeps, the Istart, Istop, Istep, Vstart, Vstop, and Vstep values can be changed as required. For different sweep lengths, array size and loop counter values must be adjusted accordingly.

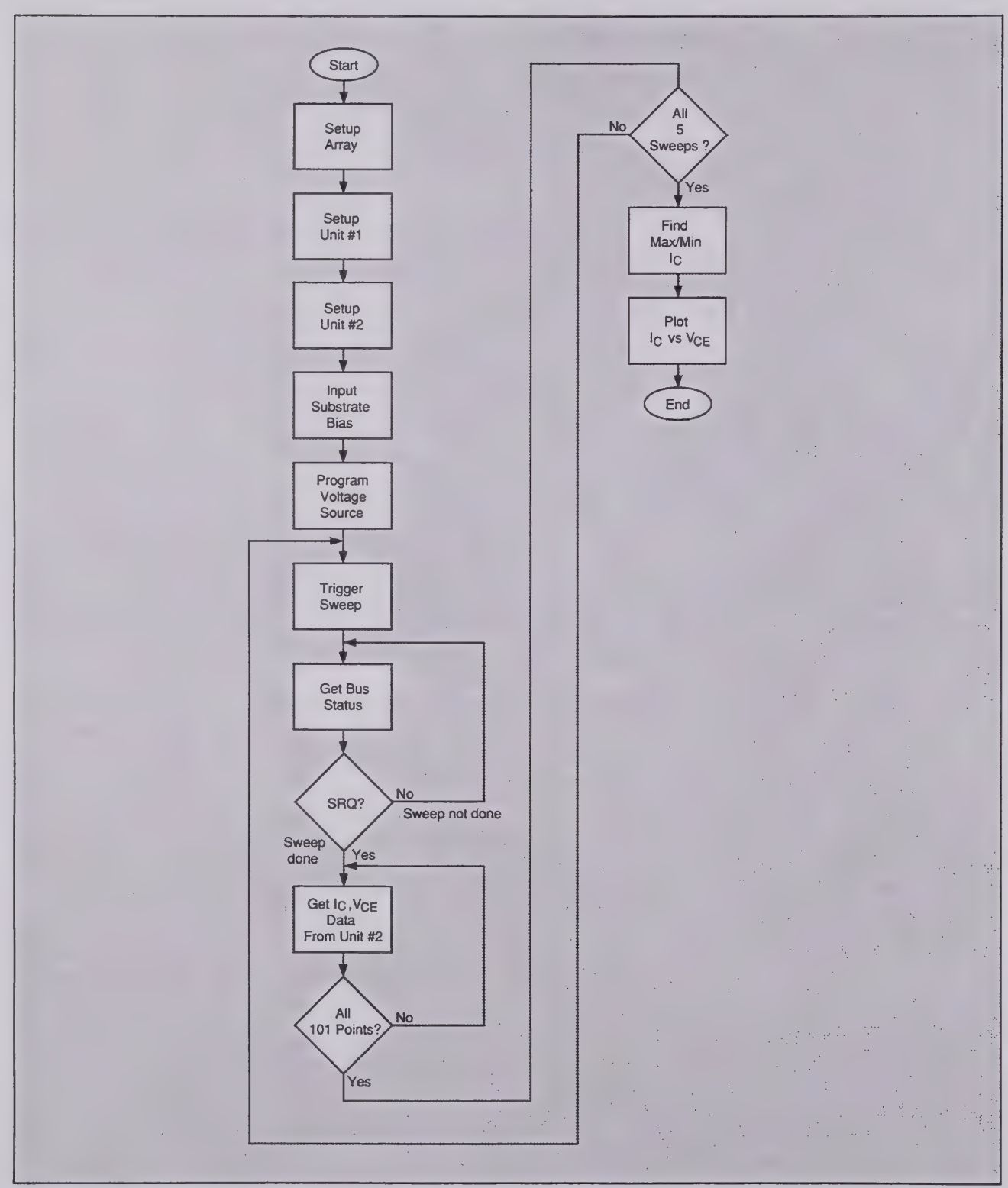


Figure 5-14. Program 16 Flowchart

```
10    REM COMMON EMITTER CHARACTERISTIC TEST PROGRAM REV. 1.3 (Program 16)
20    REM INCLUDES SUBSTRATE BIAS PROGRAMMING FOR 230 VOLTAGE SOURCE
30    OPTION BASE 1                    ! First array subscript is 1
40    DIM Reading(5,101,2)             ! Dimension reading array (5 swps,101pts)
50    CLEAR 7                          ! Clear instruments
60    OUTPUT KBD;CHR$(255);CHR$(75);   ! Clear screen
70    REM ***** Unit 1 setup (sweeps Ib) ****************************
80    REMOTE 716                       ! Put Unit 1 in remote
90    OUTPUT 716;"F1,1X"               ! Source I, sweep mode
100   OUTPUT 716;"L1,1X"               ! 1V compliance, 1.1V range
110   OUTPUT 716;"O0X"                 ! Local sense
120   OUTPUT 716;"T1,1,2,0X"           ! GET trigger cycle,out trig end of delay
125   OUTPUT 716;"B0,0,0X"             ! Program 0 bias value
130   Istart=1.0E-5                    ! Define 10uA start Ib current
140   Istop=5.0E-5                     ! Define 50uA stop Ib current
150   Istep=1.0E-5                     ! Define 10uA step Ib current
160   Dly=100                          ! Define 100msec Unit delay
170   OUTPUT 716;"Q1,";Istart;",";Istop;",";Istep;",0,";Dly;"X" ! Program sweep
180   REM ***** Unit 2 setup (sweeps Vce, measures Ic) ***************
190   REMOTE 717                       ! Put Unit 2 in remote
200   OUTPUT 717;"F0,1X"               ! Source V, sweep mode
210   OUTPUT 717;"O0X"                 ! Local sensing
220   OUTPUT 717;"L100E-3,0X"          ! 100mA compliance,autorange measure
230   OUTPUT 717;"G5,2,1X"             ! Source,measure,no prefix,sweep data
240   OUTPUT 717;"M2,X"                ! SRQ on sweep done
250   OUTPUT 717;"T3,0,0,0X"           ! Trigger on external
260   OUTPUT 717;"S2X"                 ! Line cycle integration
265   OUTPUT 717;"B0,0,0X"             ! Program 0 bias value
270   OUTPUT 717;"Z1X"                 ! Enable suppress
280   Vstart=0                         ! Define 0V start Vce
290   Vstop=10                         ! Define 10V stop Vce
300   Vstep=.1                         ! Define 0.1V step Vce
310   OUTPUT 717;"Q1,";Vstart;",";Vstop;",";Vstep;",0,";Dly;"X" ! Program sweep
320   REM ****** 230 voltage source setup (provides substrate bias) ***********
330   REMOTE 713                       ! Put 230 in remote
340   INPUT "Enter substrate bias",Vsub! Input desired substrate bias voltage
350   OUTPUT 713;"V";Vsub;"X"          ! Program 230 with substrate bias
360   PRINT "Close lid, press CONT to begin test"
370   PAUSE
380   OUTPUT 716;"R1N1X"               ! Arm Unit 1 trigger,turn on output
390   OUTPUT 717;"R1N1X"               ! Arm Unit 2 trigger, turn on output
400   OUTPUT 713;"F1X"                 ! Turn on 230 output
410   FOR I=1 TO 5                     ! Loop for five Ib curves
420   PRINT "Generating sweep";I
430   TRIGGER 716                      ! Trigger Unit to start sweep
440   STATUS 7,7;Stat                  ! Get IEEE-488 bus status
450   IF NOT BIT(Stat,10) THEN 440     ! Wait for Unit 2 SRQ on sweep done
460   Stat=SPOLL(717)                  ! Serial poll Unit 2 to clear SRQ
470   FOR J=1 TO 101                   ! Loop for all 101 readings
480   ENTER 717;Reading(I,J,1),Reading(I,J,2)! Get reading data from Unit 2
490   NEXT J                           ! Loop back for next reading
500   NEXT I                           ! Loop back for next Ib value
510   OUTPUT 716;"N0X"                 ! Turn off Unit 1 output
```

```
520   OUTPUT 717;"N0X"                ! Turn off Unit 2 output
530   OUTPUT 713;"F0X"                ! Turn off 230 output
540   PRINT "Press CONT to display graph"
550   PRINT "Press CONT while in graph to return to BASIC"
560   PAUSE
570   Ymin=MAXREAL                    ! Find minimum and maximum Ic value
580   Ymax=-MAXREAL
590   FOR I=1 TO 5
600   FOR J=1 TO 101
610   IF Reading(I,J,2)<Ymin THEN Ymin=Reading(I,J,2)
620   IF Reading(I,J,2)>Ymax THEN Ymax=Reading(I,J,2)
630   NEXT J
640   NEXT I
650   OUTPUT KBD;CHR$(255);CHR$(75); ! Clear screen
660   GINIT                           ! Initialize graphics
670   PLOTTER IS CRT,"INTERNAL"       ! Define plot to CRT
680   GRAPHICS ON                     ! Turn on graphics
690   MOVE 10,90                      ! Title graph
700   LABEL "230 BIAS COMMON EMITTER CHARACTERISTICS"
710   MOVE 70,10                      ! Label X axis
720   LABEL "Vce"
730   MOVE 0,53                       ! Label Y axis
740   LABEL "Ic"
750   VIEWPORT 30,120,20,85           ! Define soft clip limits
760   WINDOW Vstart,Vstop,Ymin,Ymax   ! Scale graph
770   Y1=(Ymax-Ymin)/10               ! Compute Y axis increment
780   X1=(Vstop-Vstart)/10            ! Compute X axis increment
790   GRID 2*X1,2*Y1,Vstart,Ymin      ! Draw grid
800   AXES X1,Y1,Vstart,Ymin          ! Add tick marks
810   FOR I=1 TO 5                    ! Loop for all five curves
820   FOR J=1 TO 101                  ! Loop for all 101 points per curve
830   PLOT Reading(I,J,1),Reading(I,J,2) ! Plot point
840   NEXT J                          ! Plot next point
850   PENUP
860   NEXT I                          ! Plot next curve
870   CSIZE 4                         ! Define character size
880   LORG 6                          ! Center characters
890   CLIP OFF                        ! Turn off soft clipping
900   FOR I=Vstart TO Vstop+.01*X1 STEP X1 ! Number X axis
910   MOVE I,Ymin-(Y1/4)
920   LABEL USING "#,K";I
930   NEXT I
940   FOR I=Ymin TO Ymax+.01*Y1 STEP Y1 ! Number Y axis
950   MOVE Vstart-(1.3*X1),I+(.3*Y1)
960   LABEL USING "#,MD.DE";I
970   NEXT I
980   PAUSE
990   OUTPUT KBD;CHR$(255);CHR$(75); ! Clear alpha screen
1000  GRAPHICS OFF                    ! Clear graphics screen
1010  END
```

SECTION 6
Using Source Measure Units with Other Instruments

6.1 INTRODUCTION

An all-Source Measure Unit test system is preferable for many applications, because of the versatility of the instruments. In some cases however, it may be desirable to replace one of the Source Measure Units with a current source, voltage source, or electrometer, either because those instruments are readily available, or because they have capabilities not available in the Source Measure Unit. In the following paragraphs three such possible applications are discussed: (1) using a Model 220 Current Source in conjunction with an Source Measure Unit to test common-emitter characteristics, (2) using a Model 617 Electrometer along with a Source Measure Unit to perform common-source tests, and (3) using a Source Measure Unit with a Model 228A Voltage/Current Source to test power transistor current gain.

6.2 USING A SOURCE MEASURE UNIT WITH A CURRENT SOURCE

A current source can be substituted for a Source Measure Unit when testing for common-emitter characteristics, as shown in Figure 6-1. Here, a Model 220 Current Source is used to supply the base current, I_B, with the I_B sweep performed under program control, while the Source Measure Unit sweeps V_{CE} and measures I_C just as before.

6.2.1 Test Connections

Figure 6-2 shows the test connections for the common-emitter tests using the current source and Source Measure Unit. Model 7078-TRX triax cables are used to make connections between the instruments and test fixture. Note, however, that a Model 6172 2-slot male to 3-lug female triax adapter will be necessary to connect the 3-slot triax cable to the Model 220, which is equipped with a 2-lug triax input connector.

WARNING

Connect interlock circuits before use. Connect the fixture ⏚ screw to safety earth ground using #18 AWG minimum wire before use. Turn off all power before connecting or disconnecting wires or cables.

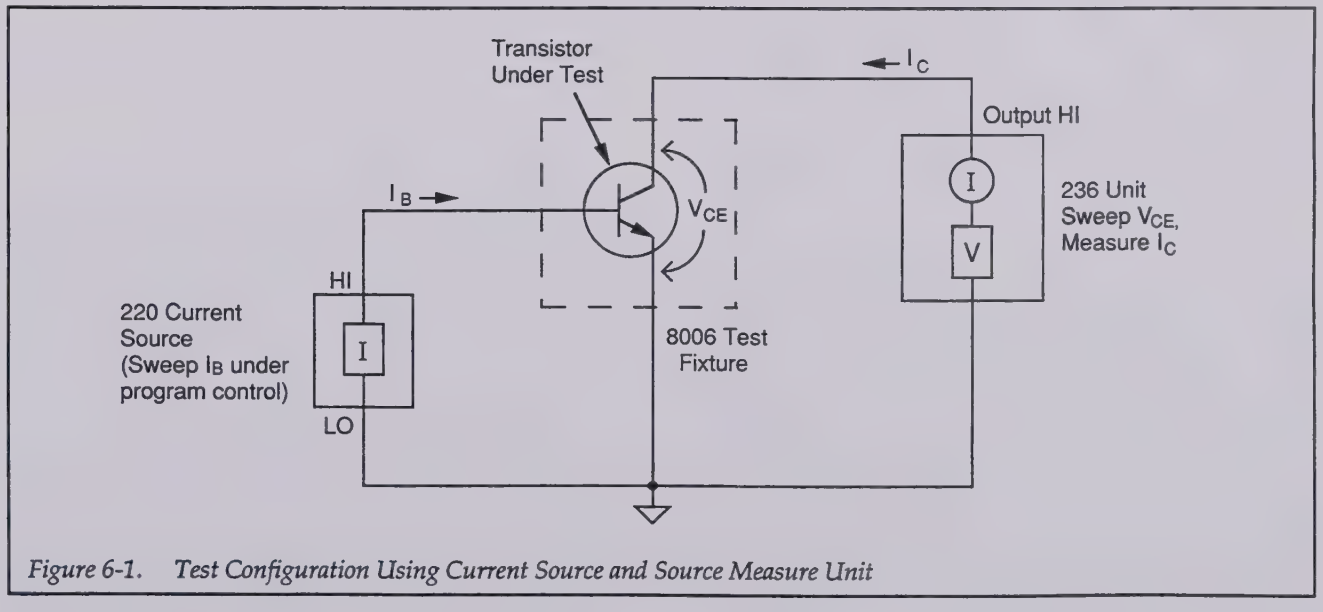


Figure 6-1. Test Configuration Using Current Source and Source Measure Unit

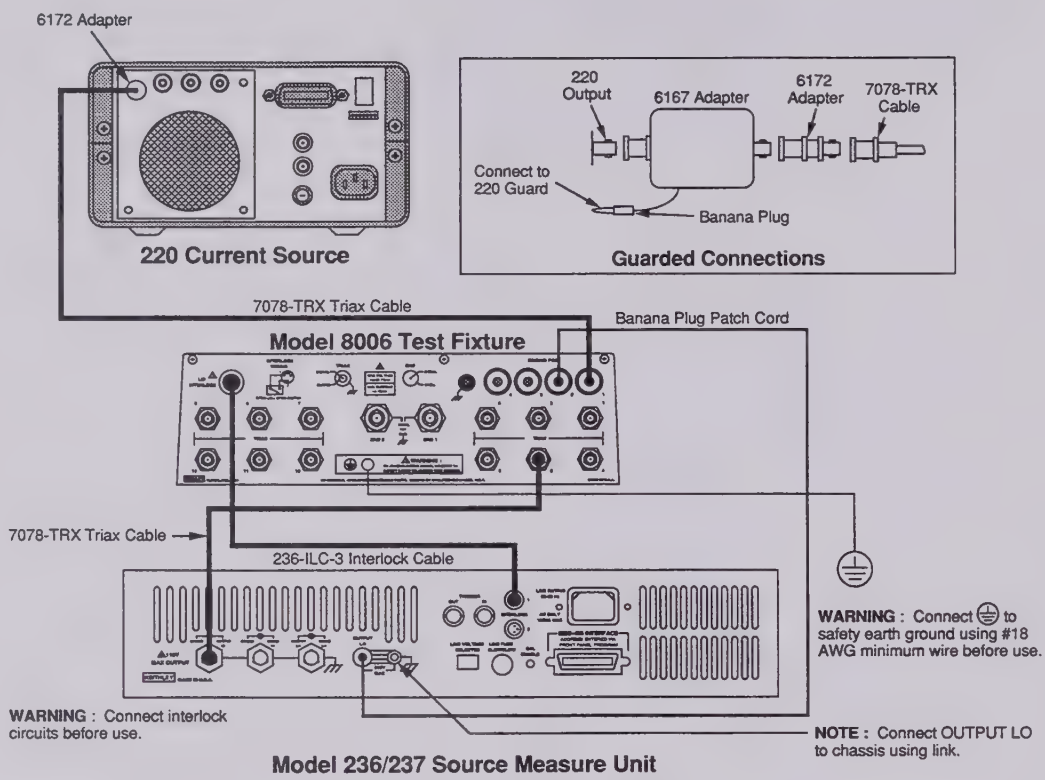

6172 Adapter
220 Current Source
220 Output
6167 Adapter
6172 Adapter
7078-TRX Cable
Connect to 220 Guard
Banana Plug
Guarded Connections
7078-TRX Triax Cable
Banana Plug Patch Cord
Model 8006 Test Fixture
7078-TRX Triax Cable
236-ILC-3 Interlock Cable
WARNING : Connect ⏚ to safety earth ground using #18 AWG minimum wire before use.
WARNING : Connect interlock circuits before use.
NOTE : Connect OUTPUT LO to chassis using link.
Model 236/237 Source Measure Unit

Figure 6-2. Test Connections for Current Source and Source Measure Unit

6.2.2 Measurement Considerations

As shown in Figure 6-2, the unguarded configuration for current source connections is used. For very critical measurements, use a Model 6167 Guarded Adapter. The Model 6167 connects directly to the OUTPUT jack on the Model 220 Current Source, and it includes a switch for selection of guarded and unguarded operation. See the inset of Figure 6-2 for guarded connections.

6.2.3 Program 17: Common-emitter Characteristics Using Current Source and Source Measure Unit

Program 17 below can be used to run common-emitter characteristic tests on small-signal NPN transistors using a current source and Source Measure Unit. In order to run the program, follow the steps below.

1. With the power off, connect both the Model 220 Current Source and the Model 236 Source Measure Unit to the IEEE-488 interface of the computer.
2. Connect the test fixture to the unit and current source using appropriate triax cables (see Figure 6-2).
3. Turn on both instruments, and allow them to warm up for two hours for rated accuracy. Make sure the primary address of the Model 236 is set to 16 and that the primary address of the Model 220 is set to 12.
4. Turn on the computer, and boot up BASIC.
5. Enter the lines below into the computer.
6. Install a small-signal NPN silicon transistor such as a 2N3904 or 2N5089 in the appropriate transistor socket of the test fixture. Be certain that the jumpers are properly installed, then close the test fixture lid.
7. RUN the program in the usual manner. The computer will program both instruments and run the common-emitter characteristic test on the device. The base current will be stepped under program control between 10μA and 50μA in 10μA increments, and the value of V_{CE} will be swept between 0V and 10V in 0.1V increments. A fixed reading delay for the Source Measure Unit of 100msec is also incorporated into the program. A fixed delay of 100msec after each programmed I_B value is also included.
8. Once the sweeps have been completed, you will be prompted to press CONT to generate a plot of the

data. A simple I_C vs. V_{CE} plot will then be displayed on the computer CRT, with separate curves for each I_B value.

9. To return to BASIC from the graph, press CONT.

6.2.4 Typical Program 17 Results

Figure 6-3 shows typical results generated by example Program 17. A 2N3904 NPN transistor was used to generate these test results.

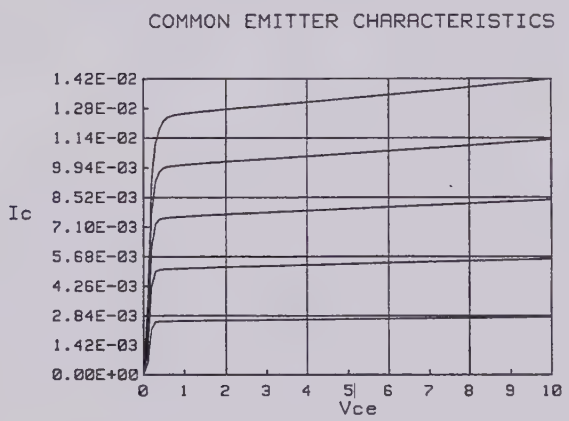


Figure 6-3. Example Plot from Test Program 17

6.2.5 Program 17 Description

For the following program description, refer to the program listing below and the flowchart shown in Figure 6-4.

Initially, the reading array is dimensioned (line 40) as a three-element array that will hold five sweeps of 101 points each, with two readings for each point. Next, both instruments are returned to default conditions by a DCL command (line 50), and the Model 236, which sweeps V_{CE} and measures I_C, is programmed as follows (lines 80-210):

- Source V, sweep mode
- Local sensing
- 100mA compliance, autorange measure
- Source measure data format with no prefix, sweep data
- SRQ on sweep done
- Trigger on GET, one sweep per trigger
- Line cycle integration

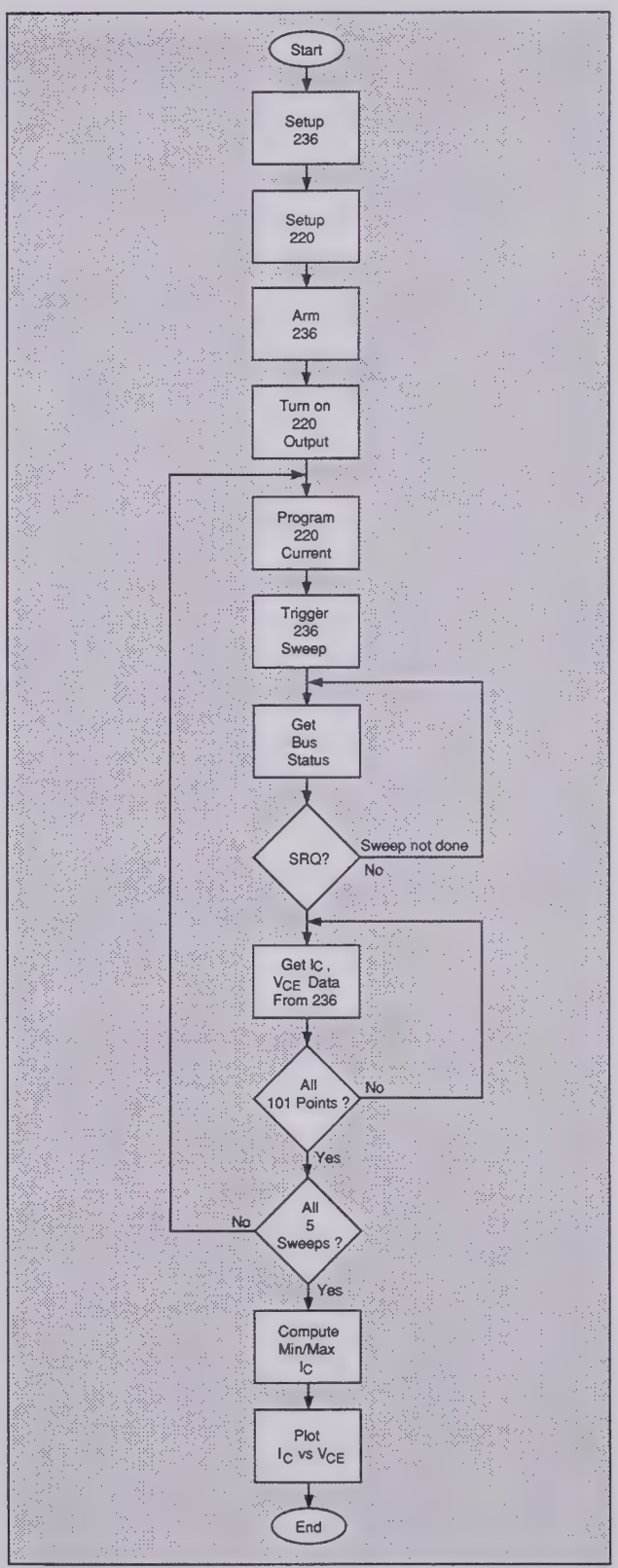


Figure 6-4. Program 17 Flowchart

- Suppress enabled
- Start V_{CE} voltage: 0V
- Stop V_{CE} voltage: 10V
- Step V_{CE} voltage: 0.1V
- Delay: 100msec
- Staircase sweep (limits determined by start, stop, and step voltage)

Following Model 236 setup, the Model 220 current source is programmed with a 10V compliance value (line 230), and the start, stop, and step current values are defined as 10μA, 50μA, and 10μA respectively (lines 240-260).

Once the two instruments are ready, the Model 236 trigger is armed and the units are placed into operate (lines 290 and 300). After the array index value is declared (line 310), the main programming loop is then entered to generate the five I_B curve sweeps (line 320). At the beginning of the main loop, the base current is programmed (line 340), and, after a 100msec delay, the unit is triggered to begin its sweep (line 360). In order to synchronize the program with each sweep, the program enters a loop to wait for the unit to generate an SRQ (lines 370 and 380) when it has finished a sweep. Once each sweep has finished, the unit is serial polled to clear the SRQ line (line 390), and the data are read into the reading array (line 400). Array element (K,J,1) stores source (V_{CE}) information, and array element (K,J,2) stores measured data (I_C) information. Once all the data pertaining to the present sweep are read, the program increments the array index (line 430), and loops back to program the current source for the next sweep at the subsequent I_B value (line 440).

In order to properly scale the plot, the maximum and minimum I_C values must be determined. This operation is performed in lines 500-570 of the program. Next, the data are plotted (lines 590-930). Note that the X axis of the graph is scaled by the Vstart and Vstop parameters (line 690), while the the Y axis is scaled by the maximum and minimum I_C values.

6.2.6 Modifying Program 17

As written, the sweep limits and increments are set to fixed values. For I_B, the start, stop, and step values are 10μA, 50μA, and 10μA respectively, and the start, stop, and step V_{CE} values are 0V, 10V, and 0.1V respectively. Again, you can modify the program as required, or include INPUT statements to allow operator input of these parameters. For sweep lengths other than 101 points, additional modifications such as array dimension and loop counter must also be made.

```
10    REM COMMON EMITTER CHARACTERISTIC TEST PROGRAM REV. 1.3 (Program 17)
20    REM USING 220 CURRENT SOURCE TO SWEEP BASE CURRENT
30    OPTION BASE 1                    ! First array subscript is 1
40    DIM Reading(5,101,2)             ! Dimension reading array (5 swps,101 pts)
50    CLEAR 7                          ! Clear Unit and current source
60    OUTPUT KBD;CHR$(255);CHR$(75);   ! Clear screen
70    REM ***** 236 setup (sweeps Vce, measures Ic) ***************
80    REMOTE 716                       ! Put 236 in remote
90    OUTPUT 716;"F0,1X"               ! Source V, sweep mode
100   OUTPUT 716;"O0X"                 ! Local sensing
110   OUTPUT 716;"L100E-3,0X"          ! 100mA compliance,autorange measure
120   OUTPUT 716;"G5,2,1X"             ! Source,measure,no prefix,sweep data
130   OUTPUT 716;"M2,X"                ! SRQ on sweep done
140   OUTPUT 716;"T1,0,0,0X"           ! Trigger on GET,continuous
150   OUTPUT 716;"S2X"                 ! Line cycle integration
155   OUTPUT 716;"B0,0,0X"             ! Program 0 bias value
160   OUTPUT 716;"Z1X"                 ! Enable suppress
170   Vstart=0                         ! Define 0V start Vce
180   Vstop=10                         ! Define 10V stop Vce
190   Vstep=.1                         ! Define 0.1V step Vce
200   Dly=100                          ! 100msec Unit delay
210   OUTPUT 716;"Q1,";Vstart;",";Vstop;",";Vstep;",0,";Dly;"X" ! Program sweep
220   REM ****** 220 setup (sweeps Ib under program control) *********
230   OUTPUT 712;"V10X"                ! Program 10V compliance
240   Istart=1.0E-5                    ! Define 10uA start current
250   Istop=5.0E-5                     ! Define 50uA stop current
260   Istep=1.0E-5                     ! Define 10uA step current
270   PRINT "Close lid, press CONT to begin test"
280   PAUSE
290   OUTPUT 716;"R1N1X"               ! Arm 236 trigger,turn on output
300   OUTPUT 712;"F1X"                 ! Turn on 220 output
310   K=1                              ! Define array index
320   FOR I=Istart TO Istop STEP Istep ! Loop for all Ib curves
330   PRINT "Generating sweep with";I;"current"
340   OUTPUT 712;"I";I;"X"             ! Program 220 current
350   WAIT .1                          ! Wait 100msec for settling
360   TRIGGER 716                      ! Trigger 236 to start sweep
370   STATUS 7,7;Stat                  ! Get IEEE-488 bus status
380   IF NOT BIT(Stat,10) THEN 370     ! Wait for 236 SRQ on sweep done
390   Stat=SPOLL(716)                  ! Serial poll 236 to clear SRQ
400   FOR J=1 TO 101                   ! Loop for all 101 readings
410   ENTER 716;Reading(K,J,1),Reading(K,J,2)! Get Vce and Ic data from 236
420   NEXT J                           ! Loop back for next reading
430   K=K+1                            ! Increment array index
440   NEXT I                           ! Loop back for next Ib value
450   OUTPUT 716;"N0X"                 ! Turn off 236 output
460   OUTPUT 712;"F0X"                 ! Turn off 220 output
470   PRINT "Press CONT to display graph"
480   PRINT "Press CONT while in graph to return to BASIC"
490   PAUSE
500   Ymin=MAXREAL                     ! Find minimum and maximum Ic value
```

```
510   Ymax=-MAXREAL
520   FOR I=1 TO 5
530   FOR J=1 TO 101
540   IF Reading(I,J,2)<Ymin THEN Ymin=Reading(I,J,2)
550   IF Reading(I,J,2)>Ymax THEN Ymax=Reading(I,J,2)
560   NEXT J
570   NEXT I
580   OUTPUT KBD;CHR$(255);CHR$(75); ! Clear screen
590   GINIT                          ! Initialize graphics
600   PLOTTER IS CRT,"INTERNAL"      ! Define plot to CRT
610   GRAPHICS ON                    ! Turn on graphics
620   MOVE 30,95                     ! Title graph
630   LABEL "COMMON EMITTER CHARACTERISTICS"
640   MOVE 70,10                     ! Label X axis
650   LABEL "Vce"
660   MOVE 0,53                      ! Label Y axis
670   LABEL "Ic"
680   VIEWPORT 30,120,20,85          ! Define soft clip limits
690   WINDOW Vstart,Vstop,Ymin,Ymax  ! Scale graph
700   Y1=(Ymax-Ymin)/10              ! Compute Y axis increment
710   X1=(Vstop-Vstart)/10
720   GRID 2*X1,2*Y1,Vstart,Ymin     ! Draw grid
730   AXES X1,Y1,Vstart,Ymin         ! Add some tick marks
740   FOR I=1 TO 5                   ! Loop for all five curves
750   FOR J=1 TO 101                 ! Loop for all 101 points per curve
760   PLOT Reading(I,J,1),Reading(I,J,2) ! Plot point
770   NEXT J                         ! Plot next point
780   PENUP
790   NEXT I                         ! Plot next curve
800   CSIZE 4                        ! Define character size
810   LORG 6                         ! Center character
820   CLIP OFF                       ! Turn off soft clipping
830   FOR I=Vstart TO Vstop+.01*Vstep STEP X1 ! Number X axis
840   MOVE I,Ymin-(Y1/4)
850   LABEL USING "#,K";I
860   NEXT I
870   FOR I=Ymin TO Ymax+.01*Y1 STEP Y1 ! Number Y axis
880   MOVE Vstart-(1.3*X1),I+(.3*Y1)
890   LABEL USING "#,MD.DDE";I
900   NEXT I
910   PAUSE
920   OUTPUT KBD;CHR$(255);CHR$(75); ! Turn off alpha display
930   GRAPHICS OFF                   ! Turn off graphics display
940   END
```

6.3 USING AN ELECTROMETER WITH A SOURCE MEASURE UNIT

A Model 617 Electrometer/Source can be used in place of a Source Measure Unit for many tests including common-source tests on FETs. The voltage source section can be used to supply the necessary V_{DS} voltages, while the electrometer section can be used to measure the source current.

The following paragraphs discuss the overall test configuration, test connections, and also list a sample program for making such tests with these instruments.

WARNING

There are no provisions for using a safety interlock with the Model 617 Electrometer/Source. To avoid a possible shock hazard, always leave the test fixture lid closed when hazardous voltages are present. Also connect the test fixture ⏚ screw to safety earth ground using #18 AWG minimum wire before use. Turn off all power before connecting or disconnecting wires or cables.

6.3.1 Test Configuration

Figure 6-5 shows the test configuration for the common-source tests using one Source Measure Unit and the electrometer/source. The unit sweeps V_{GS}, while the voltage source of the Model 617 sweeps V_{DS}, and the electrometer section measures I_D. For this programming example, a small-signal, N-channel JFET such as a 2N4392 is recommended.

6.3.2 Test Connections

Figure 6-6 shows the test connections for the common-source tests using the electrometer/source and Source Measure Unit. Model 7078-TRX triax cables are used to make connections between the instruments and test fixture. Again, a Model 6172 2-slot male to 3-lug female triax adapter will be necessary to connect the 3-slot triax cable to the Model 617, which is equipped with a 2-lug triax input connector. Finally, connect the voltage source LO jack to one of the binding posts on the test fixture, and connect voltage source HI to the COM jack on the rear panel of the Model 617.

6.3.3 Measurement Considerations

The maximum output current of the voltage source in the Model 617 is 2mA. Thus, tests should obviously be limited to 2mA or less. The Model 617 will not be damaged by attempting to source larger currents because it is current limited, but any test results will be affected by the current limitation. Note that there are no provisions in the test program for flagging over compliance. If an over-compliance condition occurs (as indicated on the front panel), it will be necessary to change the V_{GS} test parameters to reduce the test current.

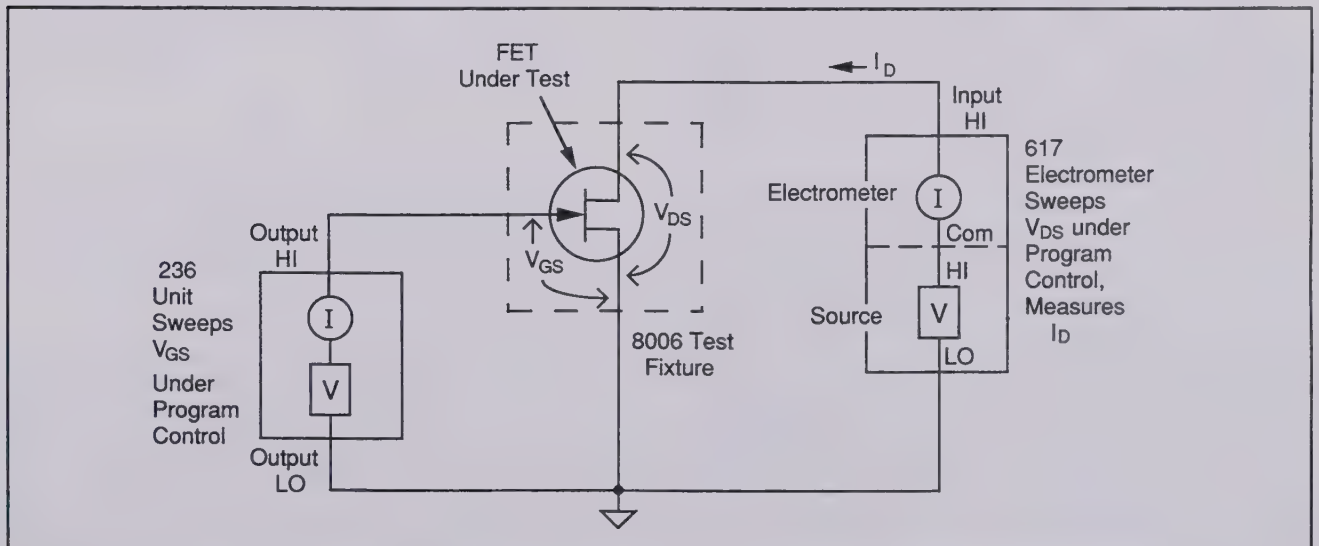


Figure 6-5. Test Configuration for Common Source Test Using Source Measure Unit and Electrometer/Source

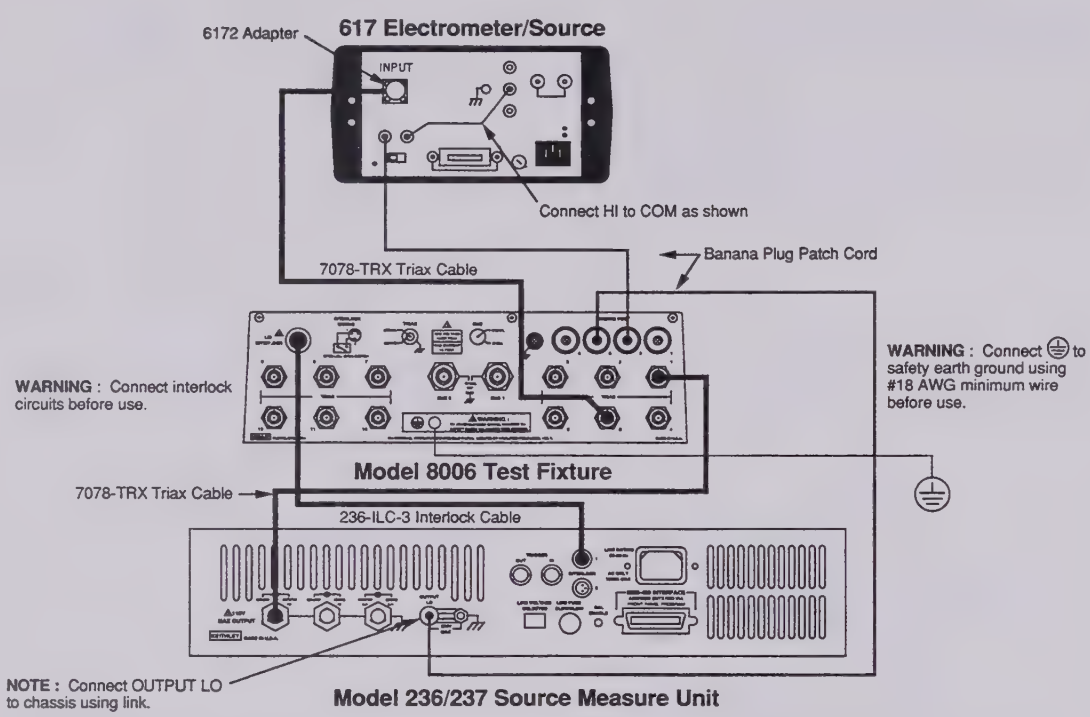

6172 Adapter
617 Electrometer/Source
INPUT
Connect HI to COM as shown
Banana Plug Patch Cord
7078-TRX Triax Cable
WARNING : Connect interlock circuits before use.
WARNING : Connect ⏚ to safety earth ground using #18 AWG minimum wire before use.
Model 8006 Test Fixture
7078-TRX Triax Cable
236-ILC-3 Interlock Cable
NOTE : Connect OUTPUT LO to chassis using link.
Model 236/237 Source Measure Unit

Figure 6-6. Test Connections for Common Source Test Using a Source Measure Unit and Electrometer/Source

6.3.4 Program 18: Common-source Characteristics Using Source Measure Unit and Electrometer/ Source

Program 18 below outlines general programming techniques for measuring common-source characteristics using a Source Measure Unit to sweep V_{GS}, and an electrometer/source to sweep V_{DS} and measure I_D. Follow the steps outlined below to use this program.

1. With the power off, connect the Model 236 and the Model 617 to the IEEE-488 bus of the computer.
2. Connect the unit and electrometer to the test fixture using suitable triax cables (see Figure 6-6 for details on test connections).
3. Turn on both instruments, and allow them to warm up for at least two hours for rated accuracy. Verify that the primary address of the Source Measure Unit is set to 16; the primary address of the Model 617 Electrometer/Source should be set to 27.
4. Turn on the computer, then boot up BASIC.
5. Enter the lines from Program 18 below into the computer.
6. Place a small-signal N-channel JFET such as a 2N4392 in the appropriate transistor socket. Install the correct jumpers, then close the test fixture lid.
7. RUN the program in the usual fashion. The computer will step through V_{GS} values between –2V and –1.9V using 0.025V steps. At each step, V_{DS} will be programmed between 0V and 10V at 1V increments. At each increment, I_D will be measured. Once data are collected, a plot of I_D vs. V_{DS} for each V_{GS} value will be displayed.

NOTE

It may be necessary to change the Vgstart, Vgstop, and Vgstep parameters in the program to keep a Model 617 over-compliance condition from occurring (>2mA).

8. To return to BASIC from the graph, press CONT.

6.3.5 Typical Program 18 Results

Figure 6-7 shows a typical plot generated by example Program 18. A 2N4392 N-channel JFET was used to generate these curves.

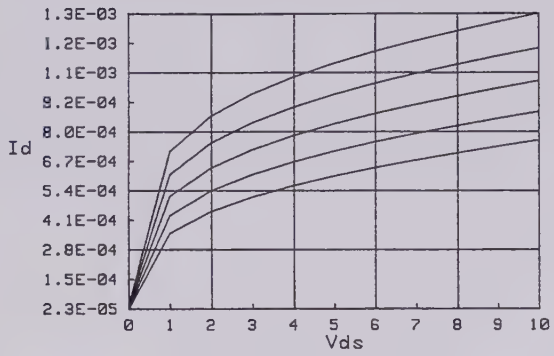


Figure 6-7. Example Plot Generated by Program 18

6.3.6 Program 18 Description

For the following description, refer to the Program 18 listing and the flowchart shown in Figure 6-8.

Initially, the array is set up for five sweeps of 11 data points each (lines 30 and 40), and both instruments are returned to default conditions (line 50). Next, the Model 236, which sweeps V_{GS}, is programmed as follows (lines 80-160):

- Source V, dc mode
- 1mA compliance, 1mA range
- Local sense
- GET trigger
- Delay: 100msec

In addition, the start, stop, and step V_{GS} voltages are defined as –2V, –1.9V, and 0.025V respectively (lines 130-150) for later programming as part of each V_{GS} program loop.

Following Model 236 setup, the Model 617, which sweeps V_{DS} and measures I_D, is configured as follows (lines 180-210):

- Amps function, 2mA range
- Zero correct on
- Data format without prefix

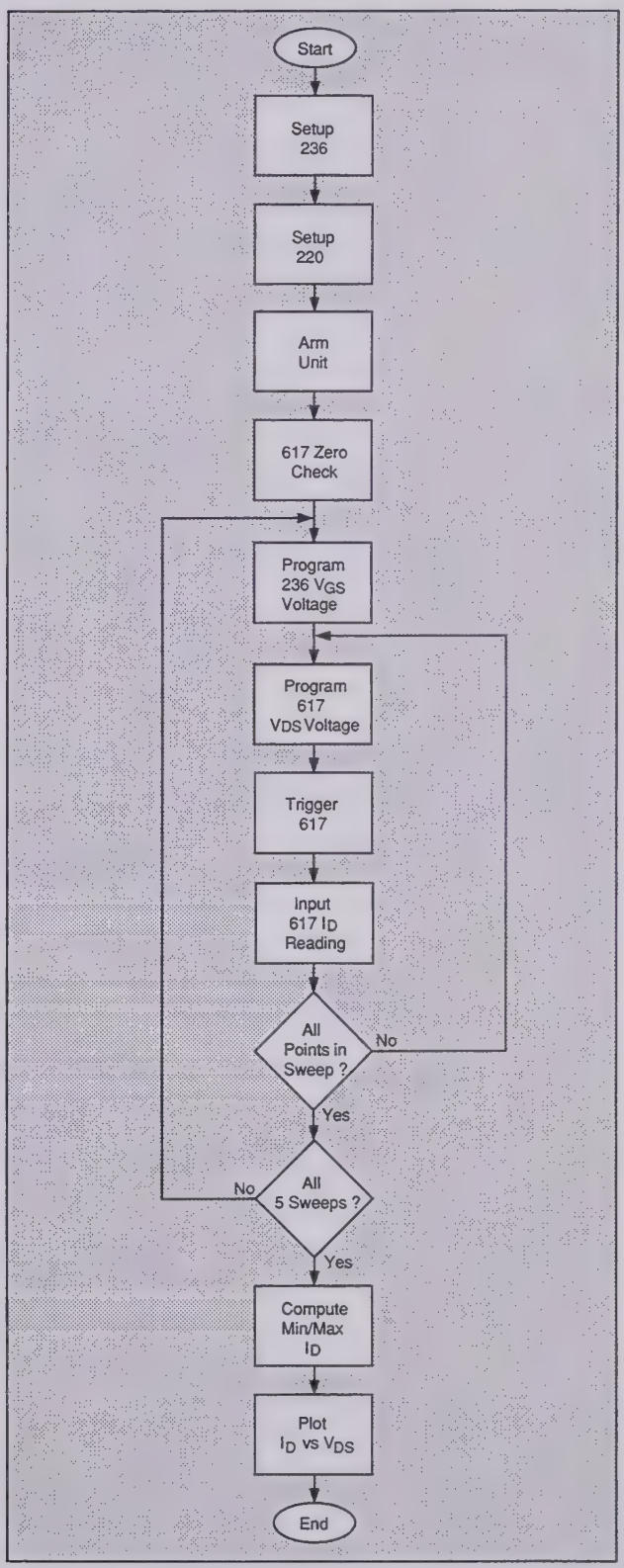


Figure 6-8. Program 18 Flowchart

Also, the start, stop, and step V_{DS} voltage values are defined as 0V, 10V, and 1V respectively (lines 220-240).

Following setup of both instruments, the operator is prompted to begin the test (lines 250 and 260), and the Model 236 is armed and placed into operate (line 270). Next, zero check on the Model 617 is turned off, and the unit is placed into operate (lines 280 and 290). The program then enters a loop to perform I_D vs. V_{DS} sweeps, one sweep for each value of V_{GS} (line 310).

At the start of each loop, the Model 236 is programmed with the present V_{GS} value (line 320), and the unit is triggered (line 340). The program then enters the second, nested loop (line 360) to sweep through all V_{DS} values. At the start of this loop, the Model 617 voltage source is programmed with the present V_{DS} value (line 370). After a two-second delay (line 380), the program then requests the current data point from the electrometer (line 390), and then takes the absolute value of the current reading. Note that V_{DS} data from the array index counter are placed into array elements (K,L,1), and measured I_D data are placed into array elements (K,L,2). After each data point has been input, the program loops back to perform the next point (line 430). Once all points in the current sweep have been completed, the program loops back to generate the next sweep (line 450). After all five sweeps are completed, both instruments are placed into standby, and zero check on the Model 617 is enabled (lines 460 and 470).

Next, an array search is performed to determine the maximum and minimum measured values of I_D (lines 510-580). Finally, the data are plotted with I_D along the Y axis, and V_{DS} along the X axis (lines 600-940). Note that the graph is scaled according to the maximum and minimum V_{DS} values (X axis), and the maximum and minimum I_D values (Y axis).

6.3.7 Modifying Program 18

For other V_{GS} values, simply modify the Vgstart, Vgstop, and Vgstep variables as required (or use INPUT statements). For values that result in more or less than five sweeps, additional modifications to array size and corresponding loop counters must also be made.

Similarly, V_{DS} can be swept over a different range by changing the Vdstart, Vdstop, and Vdstep variables to the desired values (or, again add INPUT statements). The same general considerations regarding program modifications for array size and loop counter values also apply.

```
10    REM COMMON SOURCE CHARACTERISTIC TEST PROGRAM REV. 1.3 (Program 18)
20    REM USES 617 ELECTROMETER TO SOURCE DRAIN VOLTAGE,MEASURE DRAIN CURRENT
30    OPTION BASE 1                    ! First array subscript is 1
40    DIM Reading(5,11,2)              ! Dimension reading array (5 swps,11 pts)
50    CLEAR 7                          ! Clear Unit and current source
60    OUTPUT KBD;CHR$(255);CHR$(75);   ! Clear screen
70    REM ***** 236 setup (sweeps Vgs) ****************************
80    REMOTE 716                       ! Put 236 in remote
90    OUTPUT 716;"F0,0X"               ! Source V, DC mode
100   OUTPUT 716;"L1E-3,7X"            ! 1mA compliance, 1mA range
110   OUTPUT 716;"O0X"                 ! Local sense
120   OUTPUT 716;"T1,0,0,0X"           ! GET trigger
125   OUTPUT 716;"B0,0,0X"             ! Program 0 bias value
130   Vgstart=-2.0                     ! Define -2V start Vgs voltage
140   Vgstop=-1.9                      ! Define -1V stop Vgs voltage
150   Vgstep=.025                      ! Define 0.025V step Vgs voltage
160   Dly=100                          ! Define 100msec Unit delay
170   REM ***** 617 setup (sweeps Vds, measures Id: 2mA maximum!) *****
180   REMOTE 727                       ! Put 617 in remote
190   OUTPUT 727;"F1XR10X"             ! Amps, 2mA range
200   OUTPUT 727;"Z1X"                 ! Zero correct instrument
210   OUTPUT 727;"G1X"                 ! Reading without prefix
220   Vdstart=0                        ! Define 0V start Vds
230   Vdstop=10                        ! Define 10V stop Vds
240   Vdstep=1                         ! Define 1V step Vds
250   PRINT "Close lid, press CONT to begin test"
260   PAUSE
270   OUTPUT 716;"R1N1X"               ! Arm 236 trigger,turn on output
280   OUTPUT 727;"C0X"                 ! Turn off 617 zero check
290   OUTPUT 727;"O1X"                 ! Turn on 617 voltage source
300   K=1
310   FOR I=Vgstart TO Vgstop STEP Vgstep ! Loop for all Vgs curves
320   OUTPUT 716;"B";I;",0,";Dly;"X" ! Program 236 for Vgs voltage value
330   PRINT "Generating sweep with ";I;"V"
340   TRIGGER 716                      ! Trigger 236 Unit
350   L=1                              ! Declare array index counter
360   FOR J=Vdstart TO Vdstop STEP Vdstep ! Loop for all Vds values
370   OUTPUT 727;"V";J;"X"             ! Program 617 voltage
380   WAIT 2                           ! Wait 2 sec settling time
390   ENTER 727;Reading(K,L,2)         ! Get Id data from 617
400   Reading(K,L,2)=ABS(Reading(K,L,2))! Take absolute value
410   Reading(K,L,1)=J                 ! Put Vds value in array
420   L=L+1
430   NEXT J                           ! Loop back for next reading
440   K=K+1                            ! Increment array index
450   NEXT I                           ! Loop back for next Vgs value
460   OUTPUT 727;"O0XC1X"              ! Turn off 617 output,enable zero check
470   OUTPUT 716;"N0X"                 ! Turn off 236 output
480   PRINT "Press CONT to display graph"
490   PRINT "Press CONT while in graph to return to BASIC"
500   PAUSE
```

```
510   Ymin=MAXREAL                    ! Find minimum and maximum Id value
520   Ymax=-MAXREAL
530   FOR I=1 TO 5
540   FOR J=1 TO 11
550   IF Reading(I,J,2)<Ymin THEN Ymin=Reading(I,J,2)
560   IF Reading(I,J,2)>Ymax THEN Ymax=Reading(I,J,2)
570   NEXT J
580   NEXT I
590   OUTPUT KBD;CHR$(255);CHR$(75); ! Clear screen
600   GINIT                           ! Initialize graphics
610   PLOTTER IS CRT,"INTERNAL"       ! Define plot to CRT
620   GRAPHICS ON                     ! Turn on graphics
630   MOVE 20,95                      ! Title graph
640   LABEL "COMMON SOURCE CHARACTERISTICS"
650   MOVE 70,10                      ! Label X axis
660   LABEL "Vds"
670   MOVE 3,53                       ! Label Y axis
680   LABEL "Id"
690   VIEWPORT 30,120,20,85           ! Define soft clip limits
700   WINDOW Vdstart,Vdstop,Ymin,Ymax ! Scale graph
710   Y1=(Ymax-Ymin)/10               ! Compute Y axis increment
720   X1=(Vdstop-Vdstart)/10          ! Compute X axis increment
730   GRID 2*X1,2*Y1,Vdstart,Ymin     ! Draw grid
740   AXES X1,Y1,Vdstart,Ymin         ! Add some tick marks
750   FOR I=1 TO 5                    ! Loop for all five curves
760   FOR J=1 TO 11                   ! Loop for all 11 points per curve
770   PLOT Reading(I,J,1),Reading(I,J,2) ! Plot point
780   NEXT J                          ! Plot next point
790   PENUP
800   NEXT I                          ! Plot next curve
810   CSIZE 4                         ! Define character size
820   LORG 6                          ! Center characters
830   CLIP OFF                        ! Turn off soft clip
840   FOR I=Vdstart TO Vdstop+.01*X1 STEP X1 ! Number X axis
850   MOVE I,Ymin-(Y1/4)
860   LABEL USING "#,K";I
870   NEXT I
880   FOR I=Ymin TO Ymax+.01*Y1 STEP Y1 ! Number Y axis
890   MOVE Vdstart-(1.3*X1),I+(.3*Y1)
900   LABEL USING "#,MD.DE";I
910   NEXT I
920   PAUSE
930   OUTPUT KBD;CHR$(255);CHR$(75); ! Clear alpha screen
940   GRAPHICS OFF                    ! Clear graphics screen
950   END
```

6.4 POWER TRANSISTOR TESTING

The power levels required for power transistor testing are often above the capabilities of a Model 236 or 237 Source Measure Unit. In such cases, a Model 228A Voltage/Current Source can be used in place of a Source Measure Unit. The Model 228A can provide a maximum of 101V at 1.01A (or 10.1V maximum at 10.1A), for a power level approximately ten times that of the Models 236 and 237.

The same general tests that are run on small-signal transistors can also be run on power transistors. Typical examples include current gain tests and common-emitter characteristics. In this paragraph, we will demonstrate current gain tests on power transistors.

6.4.1 Test Configuration

Figure 6-9 shows the general configuration for current gain tests of high-power transistors. The Model 236 Source Measure Unit sources the base current, and the Model 228A Voltage/Current Source supplies V_{CE}, and it also measures I_C. The current gain, β, is computed from the I_C and I_B values.

6.4.2 Test Connections

Figure 6-10 shows the test connections for the power transistor current gain tests using the Source Measure Unit and voltage/current source. Model 7078-TRX triax cables are used to make connections between the unit and user-supplied fixture (assuming that the test fixture is equipped with triax connectors). Model 228A connections can be made by wiring the quick disconnect connector directly to the user supplied test fixture; binding posts or screw terminals should be adequate for this application. Be sure to use wiring appropriate for the current and voltage levels involved (101V insulation, 1.01A current-carrying capability).

WARNING

Hazardous voltages may be present at the test fixture. Since the Model 228A does not have provisions for using an interlock circuit, be especially careful when using this test configuration. Always be certain to close the test fixture lid before applying power to the circuit under test. Connect fixture chassis to safety earth ground using #18AWG minimum wire before use. Turn off all power before connecting or disconnecting wires or cables.

NOTE

The leads on many power transistors are too large for the transistor sockets on the Model 8006 test fixture. For that reason, and because of the power levels involved, the use of a Model 8006 Test Fixture for power transistor testing is not recommended.

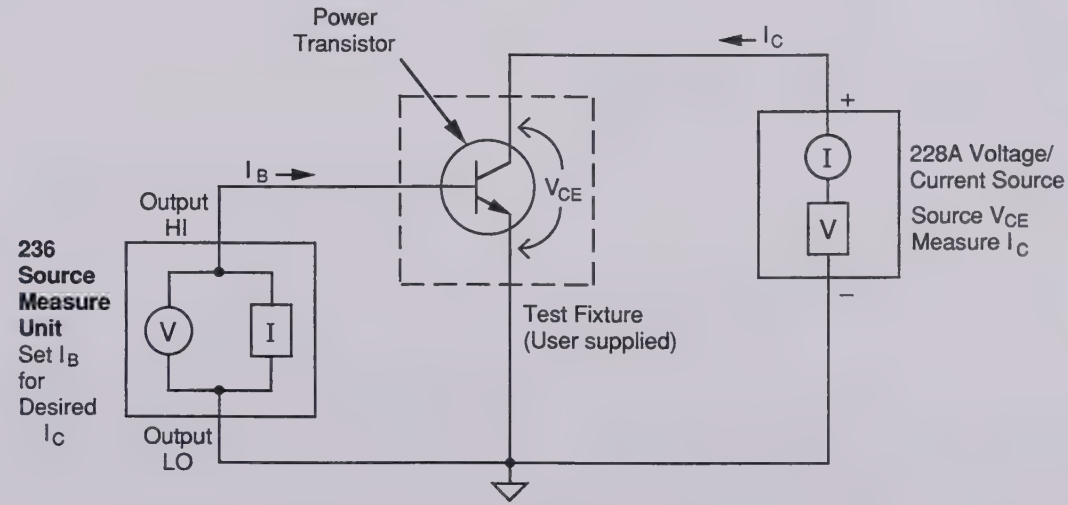


Figure 6-9. Test Configuration Using Voltage/Current Source and Source Measure Unit

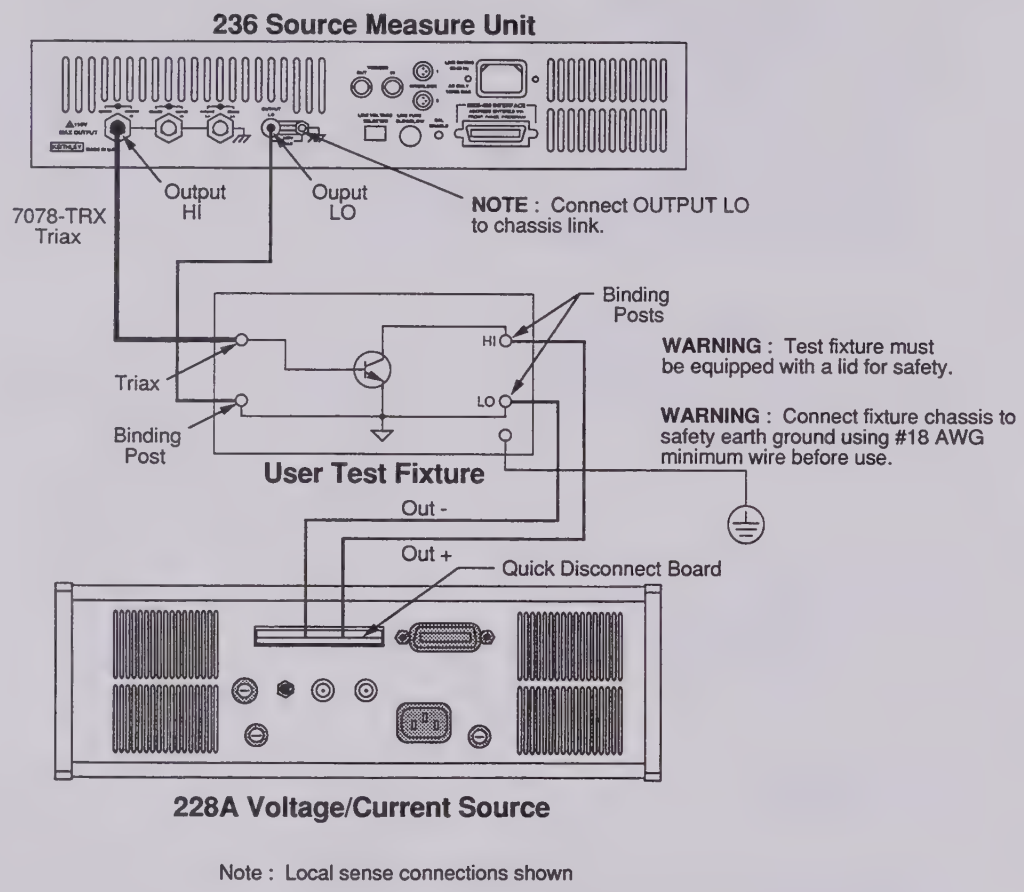

236 Source Measure Unit
Output HI
Ouput LO
NOTE : Connect OUTPUT LO to chassis link.
7078-TRX Triax
Binding Posts
HI
LO
WARNING : Test fixture must be equipped with a lid for safety.
Triax
Binding Post
WARNING : Connect fixture chassis to safety earth ground using #18 AWG minimum wire before use.
User Test Fixture
Out -
Out +
Quick Disconnect Board
228A Voltage/Current Source
Note : Local sense connections shown

Figure 6-10. Test Connections for Voltage/Current Source and Source Measure Unit

6.4.3 Measurement Considerations

This test configuration is intended for testing power transistors. Because of the higher offset currents that may be present, this setup should not be used for making critical, low-current measurements. Use the test configuration discussed in Section 3 for current-gain tests using lower current values.

6.4.4 Program 19: Power Transistor Current Gain

Program 19 below can be used to test current gain of power transistors using a Model 236 Source Measure Unit and a Model 228A Voltage/Current Source. As outlined previously, the maximum power level that can be supplied by the Model 228A is approximately 100W.

In order to run the program, follow the steps below.

1. With the power off, connect both the Model 228A Voltage/Current Source and the Model 236 Source Measure Unit to the IEEE-488 interface of the computer.
2. Connect the test fixture to the Source Measure Unit and voltage/current source using appropriate cables and wires (see Figure 6-10).
3. Turn on both instruments, and allow the units to warm up for rated accuracy. The Model 236 requires two hours warm-up, and the Model 228A requires 10 minutes warm-up. Make sure the primary address of the Model 236 is set to 16 and that the primary address of the Model 228A is set to 11.
4. Turn on the computer, and boot up BASIC.
5. Enter the lines below into the computer.
6. Install an NPN power transistor such as an MJE240 in the appropriate transistor socket of the test fixture, then close the test fixture lid.
7. RUN the program in the usual manner. The computer will prompt you to type in the the minimum and maximum I_B search values, the target value for I_C, and the V_{CE} value for the test. Keep in mind the ap-

proximate current gain as well as the 100mA Source Measure Unit current limitation when entering the base current value.

8. Once the instruments are programmed, the program will search for the optimum I_B value to perform the test at an I_C value to within 5% of the target, and display the current gain of the device. If the number of iterations has been exceeded, or if the Model 228A is found to be over compliance, a message will be displayed. If the number of iterations are exceeded, try running the program again with a closer range of I_B values.

6.4.5 Typical Program 19 Results

A typical power transistor current gain is lower than for small-signal devices. For the recommended transistor used in this test, a typical current gain would be about 25, but that will vary somewhat depending on the test parameters.

6.4.6 Program 19 Description

For the following program description, refer to the program listing below and the flowchart shown in Figure 6-11.

Initially, the reading array is dimensioned (line 30), and the iteration variables are defined (lines 40 and 50). Both instruments are returned to default conditions by a DCL command (line 60), and the Model 236, which sources I_B, is programmed as follows (lines 90-130):

- Source I, dc mode
- Local sensing
- 1V compliance, 1.1V range
- Source data format with no prefix, dc data
- Trigger on GET

The minimum and maximum I_B values, and the target I_C values are then entered (lines 140-170), and the Model 228A voltage current source, which sources V_{CE} and measures I_C, is programmed for the volts/amps data format with prefix (line 200), 1A current compliance (line 210), and the unit is programmed to output the V_{CE} voltage value (line 230).

Next, the programmed voltage is checked for a hazardous level, and an appropriate warning is displayed if the voltage will exceed 30V (lines 240-270). The user is then prompted to close the test fixture lid and begin the test (lines 280 and 290).

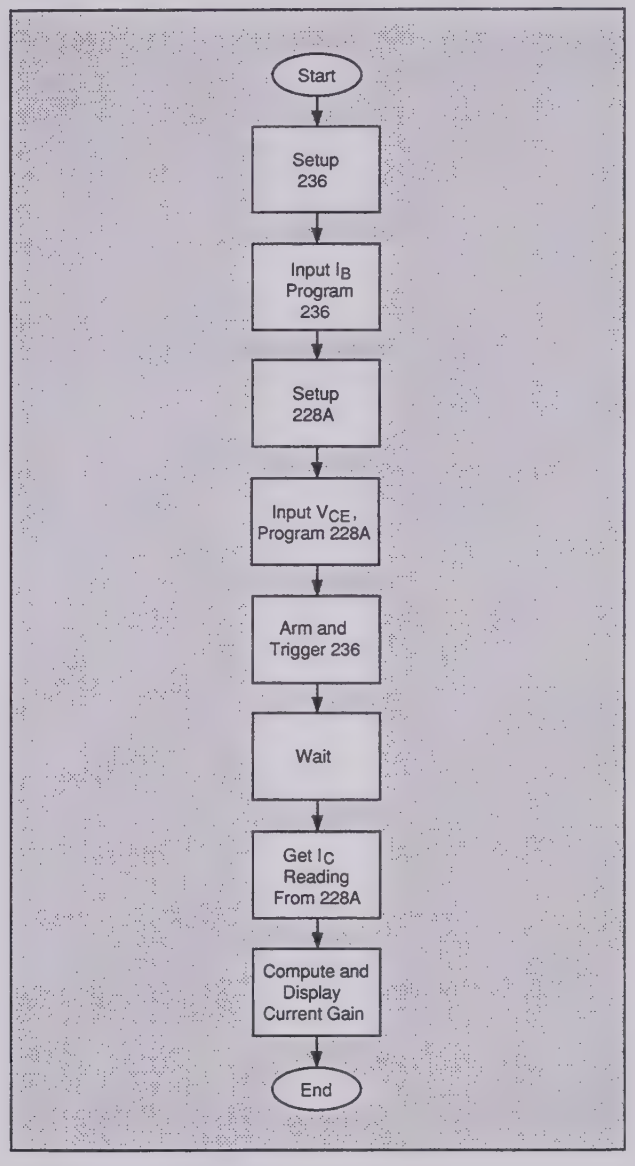


Figure 6-11. Program 19 Flowchart

Once the two instruments are programmed, the Source Measure Unit trigger is armed and the units are placed into operate (lines 300 and 310). The Source Measure Unit is triggered (line 330), and, the iteration counter is incremented and checked to see if the maximum number of iterations has been exceeded. If so, a message is displayed, and the program halts.

The Model 236 is then programmed with the present value of I_B (line 410), and, after the programmed delay period (line 420), the reading string is obtained from the instrument (line 430), and the string is then checked to see if an over-compliance condition has occurred (lines 440-490). If an over-compliance condition is found, a message to that effect is displayed, the instruments are cleared, and the program halts.

The string is then converted to a numeric (line 500), and the I_C value is checked against the target (lines 510-600). If the I_C value is not within ±5% of the target, the program calculates a new I_B value and then loops back to run the test again. Once the target is reached, the Models 228A and 236 are placed into standby (lines 610 and 620, and the current gain is calculated and displayed (line 630).

6.4.7 Modifying Program 19

The current limit of the Model 228A is set to 1A by the program. This current value will allow you to use voltages up to 101V. If larger currents (up to 10.1A) are required, modify line 210 of the program accordingly. Note however, that for currents above 1.01A, the output voltage of the Model 228A is limited to 10.01V.

The tolerance for the I_C target search is set to ±5%, but this value can be changed to a tighter value, if desired. Note, however, that it will probably be necessary to increase the number of iterations if the target range is decreased.

```
10    REM POWER TRANSISTOR CURRENT GAIN TEST PROGRAM REV. 1.3 (Program 19)
20    REM USES 236 SOURCE MEASURE UNIT AND 228A VOLTAGE/CURRENT SOURCE
30    DIM Reading$[100]                ! Dimension reading string
40    Iterations=20                    ! Define number of iterations
50    N=0                              ! Iteration counter
60    CLEAR 7                          ! Clear 236 and 228A source
70    OUTPUT KBD;CHR$(255);CHR$(75);   ! Clear screen
80    REM ***** 236 setup (sources Ib) ****************************
90    REMOTE 716                       ! Put 236 in remote
100   OUTPUT 716;"F1,0X"               ! Source I, DC mode
110   OUTPUT 716;"L1,1X"               ! 1V compliance, 1.1V range
120   OUTPUT 716;"O0X"                 ! Local sense
130   OUTPUT 716;"T1,0,0,0X"           ! GET trigger,continuous
135   OUTPUT 716;"B0,0,0X"             ! Program 0 bias value
140   INPUT "Enter maximum base current",Ib1 ! Input maximum Ib value
150   INPUT "Enter minimum base current",Ib2 ! Input minimum Ib value
160   Ib=(Ib1-Ib2)/2+Ib2               ! Compute start Ib value
170   INPUT "Enter target Ic",Itarget! Input target Ic value
180   REM ***** 228A setup (sources Vce, measures Ic) ***************
190   REMOTE 711                       ! Put 228A in remote
200   OUTPUT 711;"G4X"                 ! Select volts, amps data format
210   OUTPUT 711;"I1X"                 ! 1A compliance
220   INPUT "Enter Vce",Vce            ! Input Vce
230   OUTPUT 711;"V";Vce;"X"           ! Program 228A voltage value
240   IF ABS(Vce)>30 THEN              ! Check for dangerous voltage
250   PRINT "Hazardous voltage will be applied to device during test"
260   BEEP
270   END IF
280   PRINT "Close test fixture lid, press 'CONT"
290   PAUSE
300   OUTPUT 716;"R1N1X"               ! Arm 236 trigger,turn on output
310   OUTPUT 711;"F1X"                 ! Turn on 228A output
320   PRINT "Measuring..."
330   TRIGGER 716                      ! Trigger 236
340   N=N+1                            ! Increment iteration counter
350   IF N>Iterations THEN             ! Check for maximum iterations
360   CLEAR 7
370   BEEP
380   PRINT "Iterations exceeded";Iterations
390   STOP
400   END IF
410   OUTPUT 716;"B";Ib;",0,0X"        ! Program 236 current value
420   WAIT 1                           ! Wait one second settling time
430   ENTER 711;Reading$               ! Get reading from 228A
440   IF Reading$[1,1]="O" THEN        ! Check for over compliance
450   CLEAR 7
460   BEEP
470   PRINT "228A is over compliance"
480   STOP
490   END IF
500   Ic=VAL(Reading$[19,28])          ! Convert string to numeric
```

```
510   IF Ic>1.05*Itarget THEN          ! Check for Ic > target
520   Ib1=Ib
530   Ib=Ib-(Ib-Ib2)/10
540   GOTO 340
550   END IF
560   IF Ic<.95*Itarget THEN           ! Check for Ic < target
570   Ib2=Ib
580   Ib=Ib+(Ib1-Ib)/10
590   GOTO 340
600   END IF
610   OUTPUT 716;"N0X"                 ! Turn off 236 output
620   OUTPUT 711;"F0X"                 ! Turn off 228A output
630   PRINT "Current gain=";Ic/Ib      ! Display current gain
640   END
```

SECTION 7
Adding Switching Capabilities to a Source Measure Unit Test System

7.1 INTRODUCTION

Adding switching equipment to a Source Measure Unit test system can greatly enhance the capabilities of such a system. Two examples of how switching can increase versatility are (1) using a scanner to switch multiple DUTs, and (2) using a matrix card to allow switching flexibility to any node in the system. Each of these general switching configurations is discussed in the following paragraphs.

For the sake of brevity, many aspects of using a switching system have not been included here. For more detailed information on switching, request the Switching Handbook, which is available from Keithley Instruments, Inc. Contact your Keithley representative or the factory for more information.

7.2 SCANNER SWITCHING OF MULTIPLE DUTS

The following paragraphs discuss methods for switching multiple DUTs to a single set of Source Measure Units in a test system using a scanner. For this application, we will assume that dc current gain tests on 10 transistors in a given test fixture are to be performed.

7.2.1 System Configuration

Figure 7-1 shows the overall system configuration for the scanner/Source Measure Unit switching system. In addition to the Source Measure Units, which perform the stimulus and measurement, the system includes a Model 705 Scanner with two Model 7058 Low Current Scanner Cards to add the switching functions. For this application with the equipment shown, a total of 10 DUTs can be tested on an automated basis.

The test fixture could be custom-built, or several Model 8006 test fixtures could be used.

7.2.2 Test Configuration

Figure 7-2 shows the test configuration for this application. The equipment configuration is similar to that used for the current gain tests discussed earlier in this section except for addition of switching circuits. Note that single-pole switching on the base and collector circuits is used in order to minimize switching complexity. Keep in mind this configuration precludes the use of remote sensing; if remote sensing is required, two additional poles of switching for each DUT will be necessary.

7.2.3 Equipment Connections

Figure 7-3 shows the equipment connections for the multiple-device current gain tests. For the sake of simplicity, only one set of connections for a single device located in a Model 8006 test fixture are shown. In order to test multiple devices, additional test fixtures are required, or you could use your own custom-built design to house all ten devices in a single fixture. Note that Model 6172 2-slot male to 3-lug female adapters will be necessary to connect the 3-slot triax cables to the scanner card jacks, which are equipped with 2-lug female triax connectors.

WARNING

Connect interlock circuits before use. Connect fixture ⏚ to safety earth ground using #18 AWG minimum wire before use. If a custom fixture is used, it must be totally enclosed for safety, and the fixture chassis must be connected to safety earth ground using #18 AWG minimum wire before use. Turn off all power before connecting or disconnecting wires or cables

7.2.4 Measurement Considerations

Adding switching to any test system brings the added consideration of how such switching will affect the measurements. For low currents, the offset current of the card can become a consideration because such offsets can af-

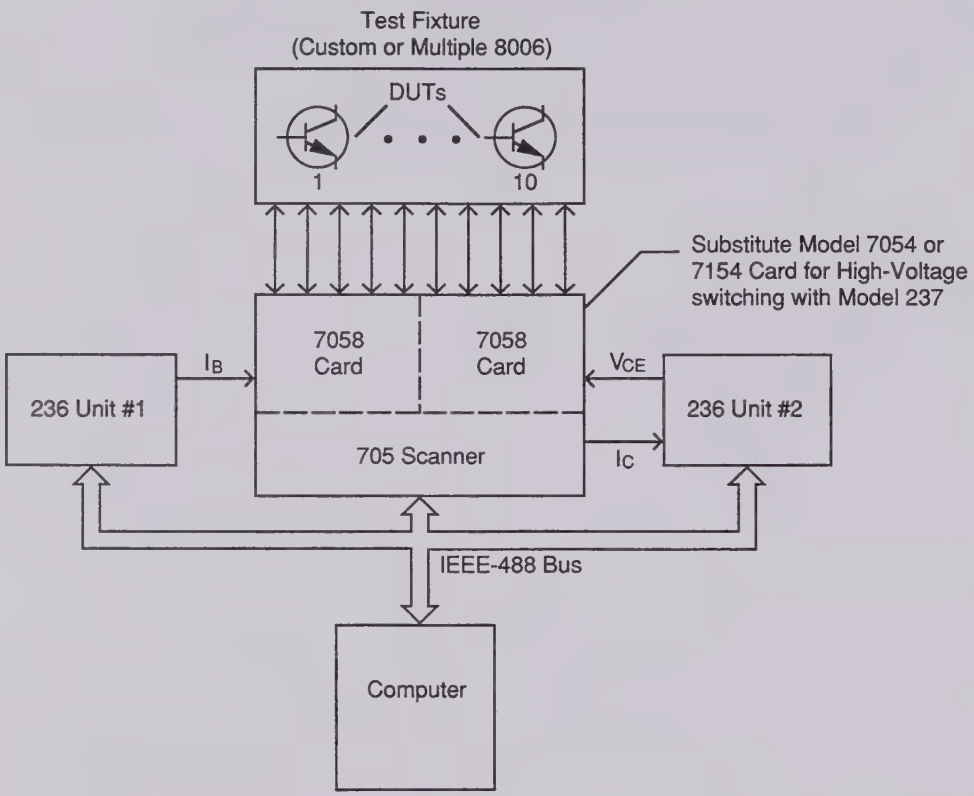


Figure 7-1. Scanner/Source Measure Unit System Configuration

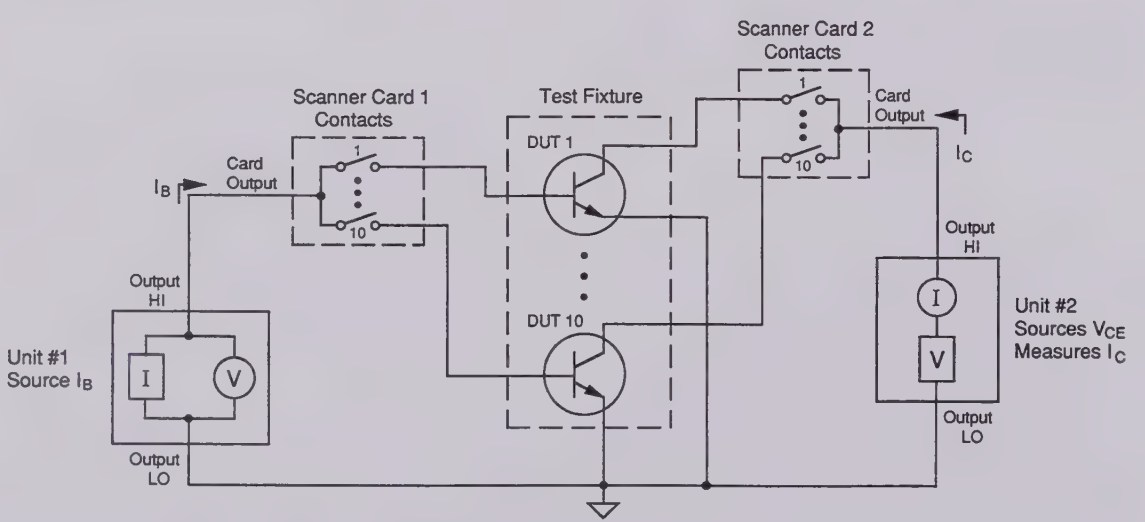


Figure 7-2. Scanner/Source Measure Unit Test Configuration

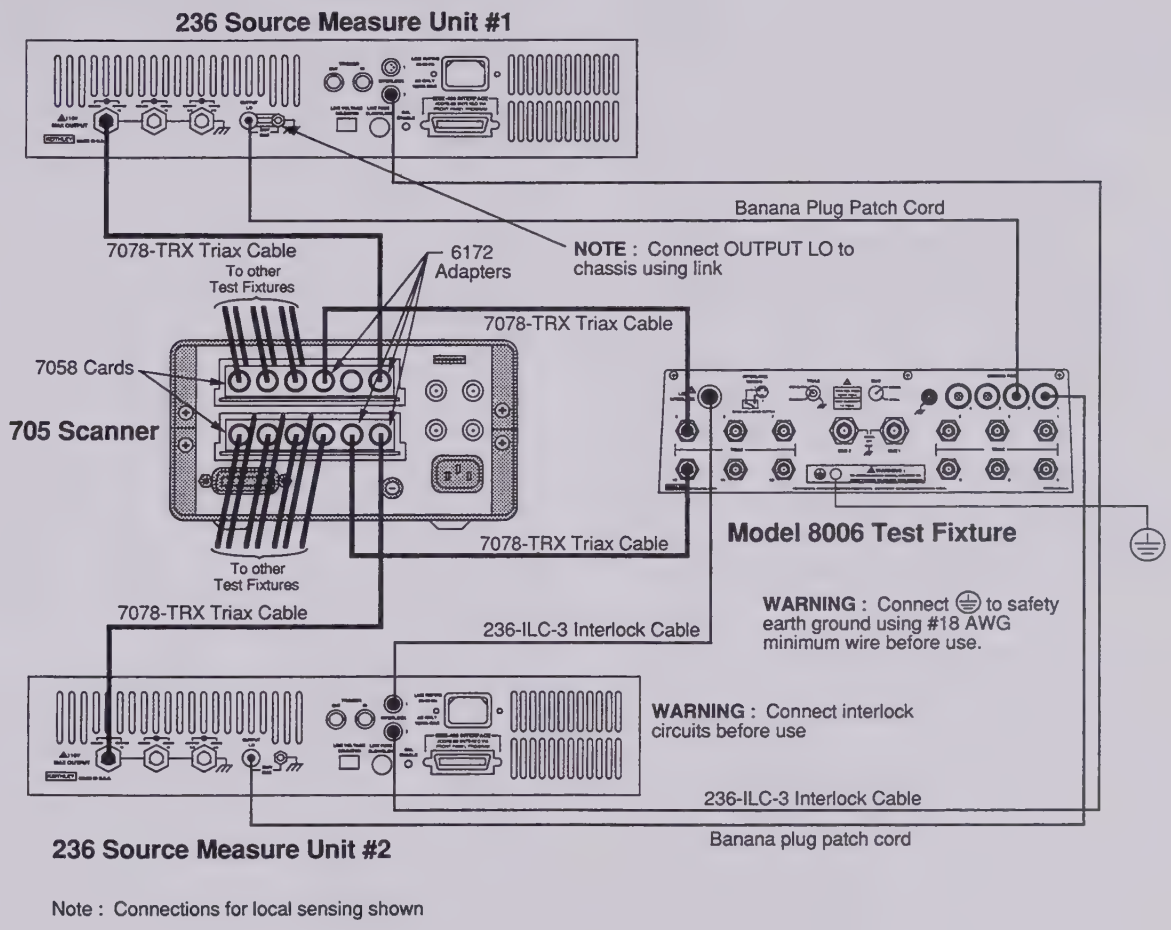

236 Source Measure Unit #1
Banana Plug Patch Cord
7078-TRX Triax Cable
To other Test Fixtures
6172 Adapters
NOTE : Connect OUTPUT LO to chassis using link
7078-TRX Triax Cable
7058 Cards
705 Scanner
Model 8006 Test Fixture
7078-TRX Triax Cable
To other Test Fixtures
7078-TRX Triax Cable
236-ILC-3 Interlock Cable
WARNING : Connect ⏚ to safety earth ground using #18 AWG minimum wire before use.
WARNING : Connect interlock circuits before use
236-ILC-3 Interlock Cable
Banana plug patch cord
236 Source Measure Unit #2
Note : Connections for local sensing shown

Figure 7-3. Scanner/Source Measure Unit Test Connections

fect measurement accuracy. The Model 7058 card used for this application has a specified offset current of 1pA which should not be a factor in most cases; however, for currents below 1nA, the offset current could affect the accuracy of your measurements. Note that guard is carried through on the inner shield to minimize these effects.

Similarly, the effects of switching can result in errors if sufficient time is not allowed for the circuit to settle before measurements. While such effects are particularly pronounced for high-impedance circuits, they can also be seen in lower-impedance circuits, although usually to a lesser degree. To allow the circuit to settle to less than 1% of final value, the settling time should be at least 5RC, where R and C are the effective circuit resistance and capacitance respectively. Allow a settling time of 7RC for settling to within 0.1% of final value.

The path isolation of the card can also come into play when testing high-impedance circuits. The path isolation resistance effectively forms a voltage divider with the resistance of the DUT. In general, path isolation resistance should be at least 100 to 1000 times the source resistance so as to have minimal effect on the measurements.

Be sure to remove the channel jumpers to avoid shorting the source. Also, for high-voltage switching with a Model 237, substitute a Model 7054 or 7154 High-voltage Scanner Card.

7.2.5 Program 20: Dc Current Gain of Multiple DUTs

Use Program 20 below to perform dc current gain tests on 10 bipolar transistors. Proceed as follows:

1. With the power off, connect both Model 236 Source Measure Units and the Model 705 Scanner to the IEEE-488 bus of the computer.
2. Connect the test fixture(s) and both Source Measure Units to the two scanner cards using appropriate triax cables (see Figure 7-3 for details on test connections). With the scanner power still off, install both Model 7058 Scanner Cards in the scanner after making test connections.
3. Turn on both Source Measure Units, and allow them to warm up for at least two hours for rated accuracy. Be sure that the primary address of Unit #1 is set to 16, and that the primary address of Unit #2 is set to 17. Also turn on the Model 705 Scanner, and verify that its primary address is set to 18.
4. Turn on the computer, then boot up BASIC.
5. Enter the lines below into the computer
6. Install 10 small-signal silicon transistors to be tested in the desired test fixture sockets (transistors should have characteristics similar to a 2N3904 or 2N5089). Install the required jumpers for all devices, then close the test fixture lid.
7. RUN the program, and follow the prompts on the screen. You will be prompted to enter 10 base current values (one for each of the 10 devices) and then the desired value of V_{CE}. When entering the base currents, keep the approximate current gains of the devices in mind so as not to saturate them. Note that no iterative search algorithm is included in this example program for the sake of simplicity.
8. Once the parameters are entered, the instruments will be programmed accordingly, and the collector current of each device will be measured. The dc current gain of each device will then be displayed on the computer CRT after all transistors are tested.

7.2.6 Typical Program 20 Results

A typical current gain for a 2N5089 would be about 500. Note however, that the current gain of the device could be as low as 300 or as high as 900.

7.2.7 Program 20 Description

For the following description, refer to the flowchart shown in Figure 7-4 and the Program 20 listing shown below.

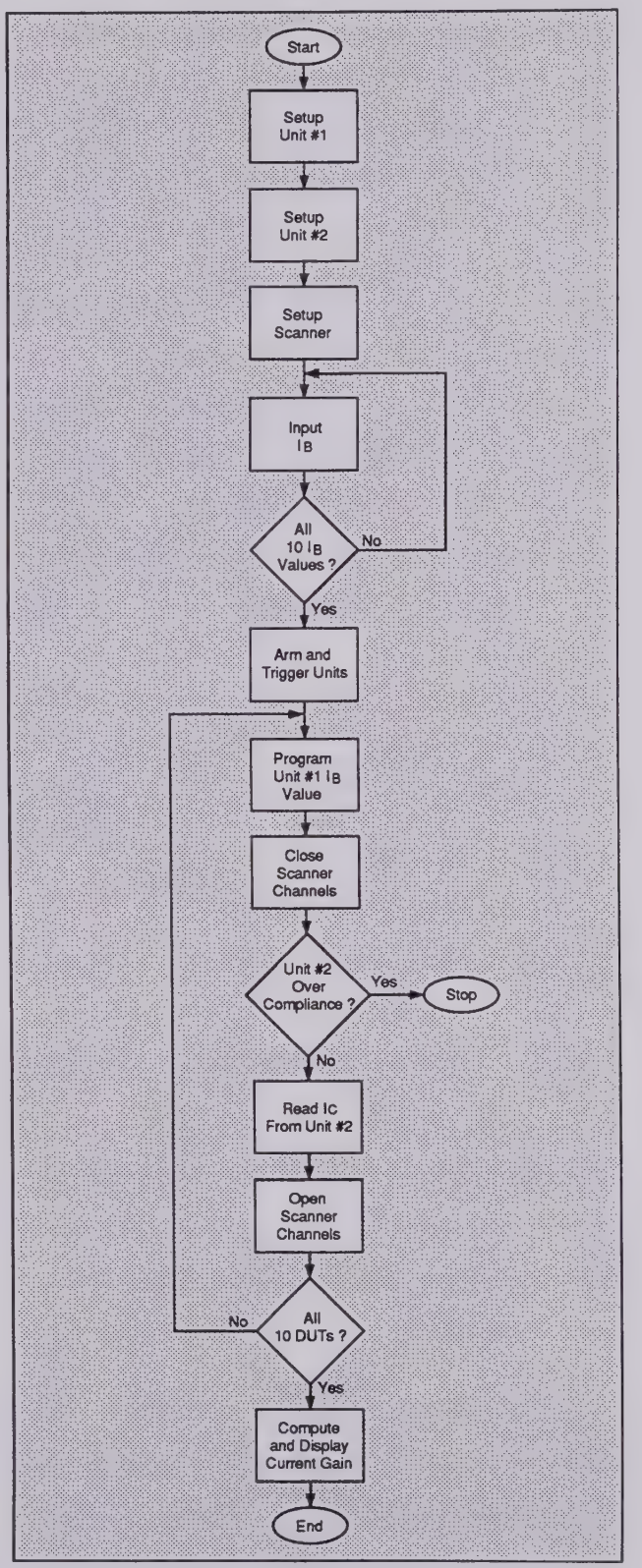


Figure 7-4. Program 20 Flowchart

After both units and the scanner are returned to default conditions (line 20), two storage arrays for I_B and I_C values are defined (line 40). Next, Unit #1, which sources I_B, is set up as follows (lines 60-100):

- Source I, dc mode
- 1V compliance, 1.1V range
- Local sense
- GET trigger, continuous

Following Unit #1 setup, Unit #2, which sources V_{CE} and measures I_C, is configured as follows (lines 130-210):

- Source V, dc mode
- Local sense
- 10mA compliance, autorange measure
- Source only data format, no prefix, dc data output
- Trigger on GET, continuous
- Line cycle integration
- Dc voltage, value determined by user-input V_{CE} value

Next, the scanner is placed in the one-pole mode (line 230), and a program loop allows the operator to input all 10 I_B values for the test (lines 240-270). Once the operator signals to continue the program (lines 280 and 290), both Source Measure Unit triggers are armed and the units are placed into operate (lines 300 and 310). Next, the units are triggered (lines 330 and 340), and the program enters the main loop to test all 10 devices (line 350).

At the start of the loop, Unit #1 is programmed with the I_B current value, and the the scanner channels for the present device are closed (lines 370 and 380). After a one-second delay, the status byte is then obtained from Unit #2 (line 400), and bit 7 in the status byte is then checked (lines 410-440) to see if it is set. If so, Unit #2 is over compliance, the operator is then notified, and the program is halted.

Assuming no error, the value of I_C for the current device is requested and placed into the I_C array (line 460), and the scanner channels are then opened (lines 470 and 480). The program then loops back to test the next device (line 490).

After all 10 devices are tested, both Source Measure Units are placed into standby (lines 500 and 510), and the dc current gain for each of the 10 devices is calculated and displayed (lines 520-540).

7.2.8 Modifying Program 20

As written, the program assumes that 10 devices are to be tested, each with a different I_B current value. For a different number of devices, simply modify the loop counter values as required. To test all devices with the same value of I_B, change the program to input only one I_B value, and program Unit #1 with that value alone.

```
10    REM DC CURRENT GAIN WITH SCANNING TEST PROGRAM REV. 1.3 (Program 20)
20    CLEAR 7                          ! Clear both Units and scanner
30    OUTPUT KBD;CHR$(255);CHR$(75);   ! Clear screen
40    DIM Ib(10),Ic(10)                ! Dimension Ib and Ic storage arrays
50    REM ***** Unit 1 setup (sources Ib) ****************************
60    REMOTE 716                       ! Put Unit 1 in remote
70    OUTPUT 716;"F1,0X"               ! Source I, DC mode
80    OUTPUT 716;"L1,1X"               ! 1V compliance, 1.1V range
90    OUTPUT 716;"O0X"                 ! Local sense
100   OUTPUT 716;"T1,0,0,0X"           ! GET trigger,continuous
110   Dly=100                          ! Define 100msec Unit delay
120   REM ***** Unit 2 setup (sources Vce, measures Ic) ***************
130   REMOTE 717                       ! Put Unit 2 in remote
140   OUTPUT 717;"F0,0X"               ! Source V, DC mode
150   OUTPUT 717;"O0M128,0X"           ! Local sensing,SRQ
160   OUTPUT 717;"L10E-3,0X"           ! 10mA compliance,autorange measure
170   OUTPUT 717;"G4,2,0X"             ! Measure,no prefix,DC data
180   OUTPUT 717;"T1,0,0,0X"           ! Trigger on GET,continuous
190   OUTPUT 717;"S2Z0X"               ! Line cycle integration,suppress off
200   INPUT "Enter Vce",Vce            ! Input Vce
210   OUTPUT 717;"B";Vce;",0,";Dly;"X" ! Program DC,autorange,delay
220   REMOTE 718                       ! Put 705 scanner in remote
230   OUTPUT 718;"A1X"                 ! Select 1-pole mode
240   FOR I=1 TO 10                    ! Loop for all 10 Ib values
250   DISP "Enter device";I;"current"; ! Prompt for Ib value
260   INPUT Ib(I)                      ! Input Ib value
270   NEXT I                           ! Loop back for next Ib value
280   PRINT "Close lid(s), press CONT to begin test"
290   PAUSE
300   OUTPUT 716;"R1N1X"               ! Arm Unit 1 trigger,turn on output
310   OUTPUT 717;"R1N1X"               ! Arm Unit 2 trigger,turn on output
320   PRINT "Measuring..."
330   TRIGGER 716                      ! Trigger Unit 1
340   TRIGGER 717                      ! Trigger Unit 2
350   FOR I=1 TO 10                    ! Loop to test all 10 devices
360   OUTPUT 716;"B";Ib(I);",0,";Dly;"X" ! Program Unit 1 with Ib value
370   OUTPUT 718;"C";I;"X"             ! Close scanner channel I
380   OUTPUT 718;"C";I+10;"X"          ! Close scanner channel I+10
390   WAIT Dly/1000+1                  ! Wait for settling
400   Stat=SPOLL(717)                  ! Serial poll Unit 2
410   IF BIT(Stat,7) THEN              ! Check for over compliance
420   BEEP
430   PRINT "Unit is over current compliance on device #";I
440   STOP
450   END IF
460   ENTER 717;Ic(I)                  ! Get Ic reading from Unit 2
470   OUTPUT 718;"N";I;"X"             ! Open scanner channel I
480   OUTPUT 718;"N";I+10;"X"          ! Open scanner channel I+10
490   NEXT I                           ! Loop back to test next device
```

```
500   OUTPUT 716;"N0X"                    ! Turn off Unit 1 output
510   OUTPUT 717;"N0X"                    ! Turn off Unit 2 output
520   FOR I=1 TO 10                       ! Loop for all 10 current gains
530   PRINT "Device #";I;"current gain=";Ic(I)/Ib(I) ! Display current gain
540   NEXT I                              ! Loop back and display next gain
550   END
```

7.3 RESISTIVITY TESTING USING MATRIX SWITCHING IN A SOURCE MEASURE UNIT TEST SYSTEM

One example that demonstrates matrix switching benefits is resistivity tests on semiconductors. The following paragraphs discuss such resistivity tests using a Source Measure Unit/matrix switching system.

7.3.1 System Configuration

Figure 7-5 shows a typical system configuration for performing resistivity tests using a Source Measure Unit. In addition to the Source Measure Unit, the system includes a Model 705 Scanner, Model 7152 Low Current Matrix Card, and a Model 8006 test fixture to house the device under test.

With the test configuration shown in Figure 7-5, only one 4-terminal sample can be tested at any given time. However, additional Model 7152 cards can expand columns or rows, allowing more than one sample to be tested by a single test procedure.

7.3.2 Test Configuration

Figure 7-6 shows a typical resistivity test configuration for a single leg measurement of one sample. Here, the current source of the Source Measure Unit sources a current between two terminals of the sample, while the voltmeter section of the unit measures the voltage across two of the opposite terminals. Generally, eight such measurements are made, as shown in Figure 7-7.

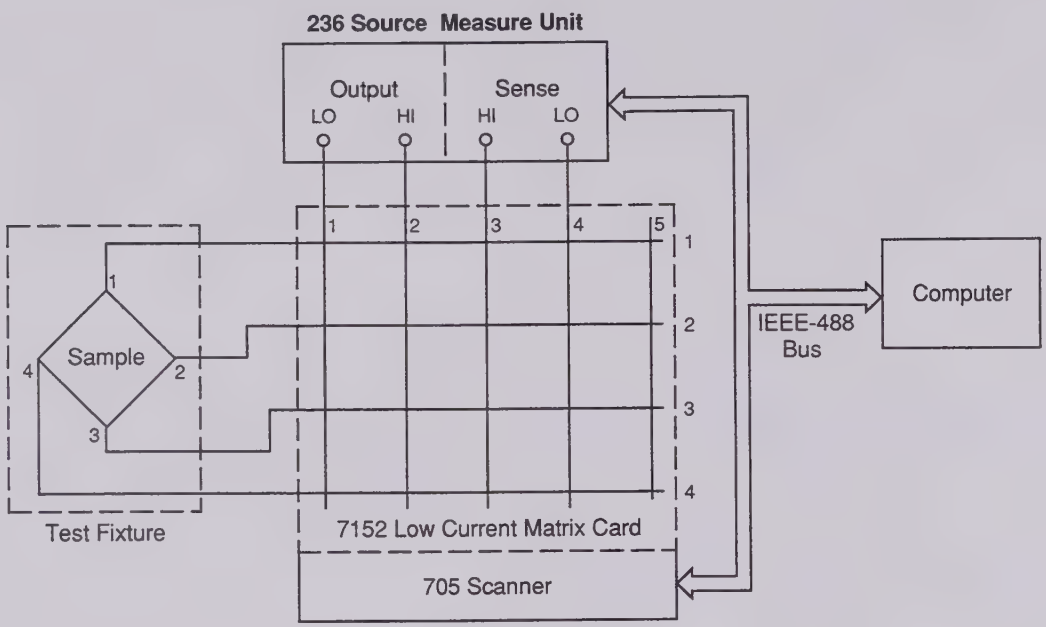


Figure 7-5. System Configuration for Resistivity Tests

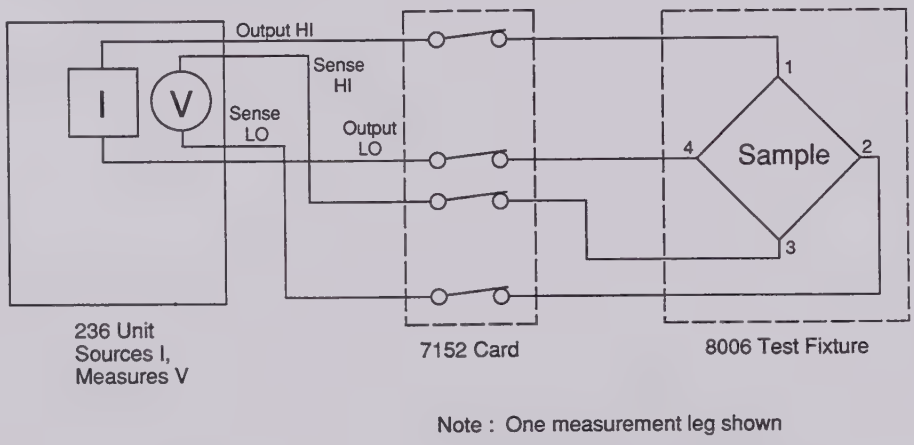


Figure 7-6. Resistivity Test Configuration

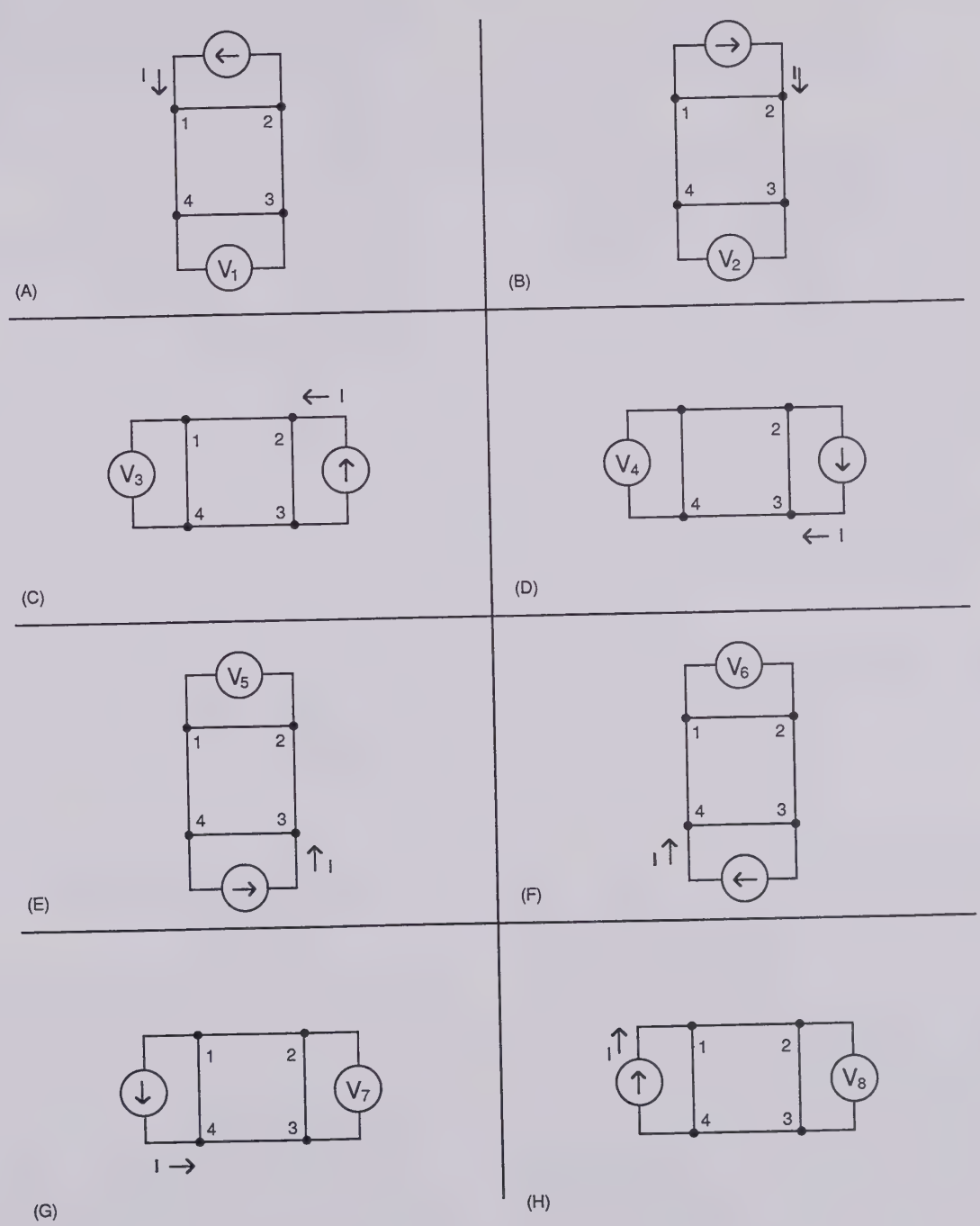


Figure 7-7. Measurements for Resistivity Tests

7.3.3 Resistivity Calculations

Resistivity is calculated from the voltage measurements as follows:

$$\sigma_A = \frac{1.1331\, f_A t_S (V_2 + V_4 - V_1 - V_3)}{I}$$

$$\sigma_B = \frac{1.1331\, f_B t_S (V_6 + V_8 - V_5 - V_7)}{I}$$

Where: σA and σB are the resistivities in Ω-cm
t_S is the sample thickness in cm
V_1 through V_8 are the voltages measured by the Model 236
I is the current sourced by the Model 236 in amperes
f_A and f_B are geometrical factors based on sample symmetry ($f_A = f_B = 1$ for perfect symmetry)

Once σA and σB are known, the average resistivity, σAVG, can be computed as follows:

$$\sigma_{AVG} = \frac{\sigma_A + \sigma_B}{2}$$

7.3.4 Test Connections

Figure 7-8 shows the test connections for the resistivity tests. The Model 8006 test fixture should be connected directly to the ROW IN or ROW OUT jacks on the Model 7152 Low Current Matrix Card using an optional Model 7152-TRX-10 cable assembly. Connect the Model 236 to the COL IN or COL OUT jacks of the matrix card, again using a Model 7152-TRX-10 cable assembly. For the OUTPUT HI, SENSE HI, and SENSE LO jacks, you can simply connect the triax cables to the corresponding jacks. For the OUTPUT LO connection, however, it will be necessary to use BNC/banana (Pomona Model 1899) and 3-lug female triax to male BNC (Pomona Model 5299) adapters.

WARNING

When a Model 236/237 is programmed for remote sensing, hazardous voltage may be present on the SENSE and OUTPUT terminals when the unit is in operate regardless of the programmed voltage or current. To avoid a possible shock hazard, always turn off all power before connecting or disconnecting cables to the Source Measure Unit or the associated test fixture. Connect interlock circuits before use. Connect fixture ⏚ screw to safety earth ground using #18 AWG minimum wire before use.

7.3.5 Measurement Considerations

The same general considerations discussed in paragraph 7.2 for the scanner card also apply to matrix card measurements. The offset current (<1pA for the Model 7152) comes into play for very low current measurements. The required settling time depends on the impedance levels involved (should be >5RC), and the path isolation can affect the accuracy of high-impedance measurements.

NOTE

In this application, the sense and source leads are connected to separate points on the DUT, which will result in a potential between OUTPUT HI and SENSE HI, and OUTPUT LO and SENSE LO. Note that the maximum voltage between the OUTPUT and SENSE leads is limited (see specifications). Reduce test current if necessary to keep the voltages below specified limits.

7.3.6 Program 21: Resistivity Tests Using a Switching Matrix and Source Measure Unit

Program 21 demonstrates programming techniques for controlling a switching matrix and Source Measure Unit to perform resistivity tests. The basic procedure for using this program is as follows:

1. With the power off, connect the Model 236 Source Measure Unit and the Model 705 Scanner to the IEEE-488 bus of the computer. Also, install the Model 7152 Card in slot 1 of the Model 707 mainframe.
2. Connect the test fixture and the Source Measure Unit to the matrix card using the specified triax cables (see Figure 7-8 and the discussion above for details on test connections).
3. Turn on the Model 236, and allow it to warm up for at least two hours for rated accuracy. Be sure that the primary address of the Source Measure Unit is set to 16. Also, turn on the Model 705, and make certain that its primary address is set to 17.

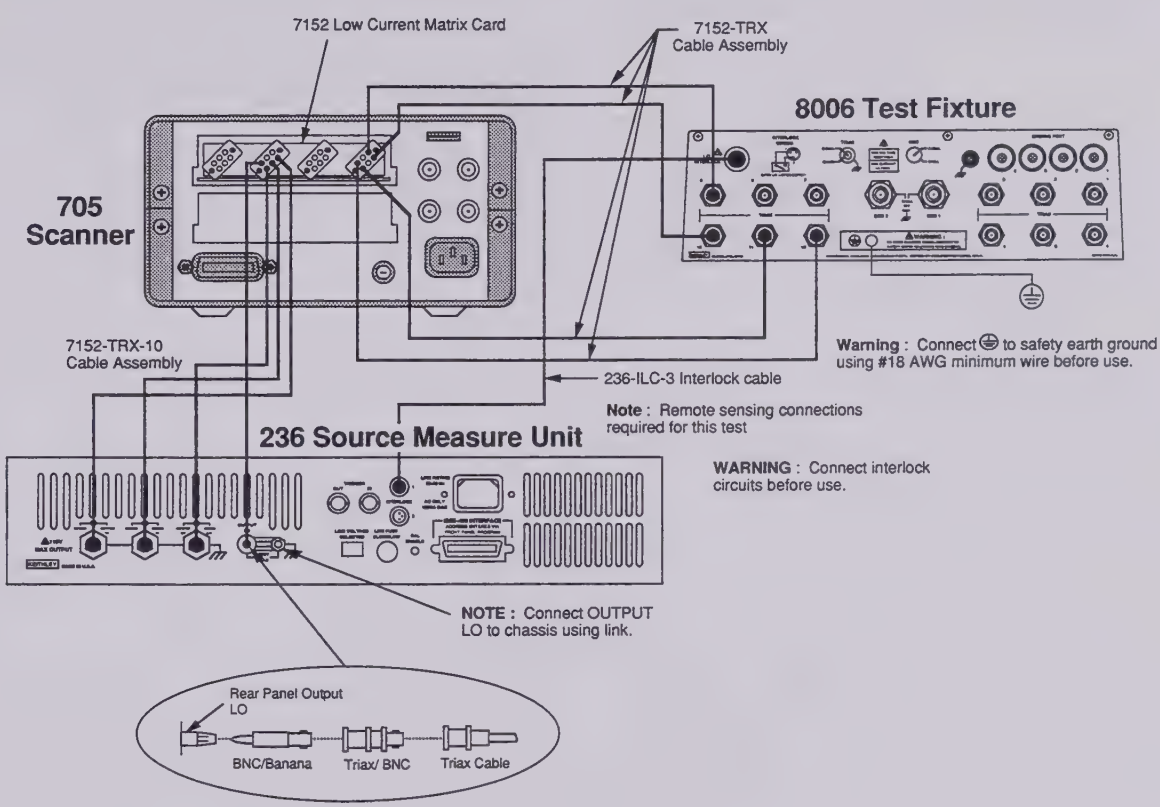

7152 Low Current Matrix Card
7152-TRX
Cable Assembly
8006 Test Fixture
705
Scanner
7152-TRX-10
Cable Assembly
Warning : Connect ⏚ to safety earth ground using #18 AWG minimum wire before use.
236-ILC-3 Interlock cable
Note : Remote sensing connections required for this test
236 Source Measure Unit
WARNING : Connect interlock circuits before use.
NOTE : Connect OUTPUT LO to chassis using link.
Rear Panel Output LO
BNC/Banana
Triax/ BNC
Triax Cable

Figure 7-8. Test Connections for Resistivity Tests

4. Turn on the computer, then boot up BASIC.
5. Enter the lines below into the computer
6. Connect the sample to be tested to the appropriate socket terminals on the test fixture, and also install the necessary test fixture jumpers. Use the general configuration shown in Figure 7-6 as a guide to test connections. Close the test fixture lid after making connections.
7. RUN the program, and follow the prompts on the screen. You will be prompted to enter the desired sample current value and then the sample thickness, which should be entered in centimeters. When entering the current, keep the approximate DUT resistance values in mind so as not to create an over voltage compliance condition. Also, you must not exceed the maximum voltage between output and sense leads of the Source Measure Unit.
8. Once the parameters are entered, the test will begin. The program will program the Source Measure Unit, and then begin the tests by closing crosspoints. A total of eight measurements will be taken and stored in an array.
9. Once the testing has been completed, the resistivity values will be calculated and displayed.

7.3.7 Program 21 Description

Refer to the Program 21 listing below and the flowchart shown in Figure 7-9 for the following description.

At the start of the program, both the Source Measure Unit and the scanner are returned to default conditions (line 20), and the reading array and command string are dimensioned (line 40). Next, the Model 236, which sources the test current and measures the sample voltage, is programmed as follows (lines 60-120):

- Source I, dc mode
- 10V compliance, autorange measure
- Remote sensing
- Measure only data format with no prefix, dc data output
- Continuous trigger on GET
- Line cycle integration

The Model 705 is then placed in remote (line 140), and the scanner is placed into matrix mode (line 150). Next, the operator is prompted to input the desired test current, at which point the Source Measure Unit is programmed with the current value (lines 160 and 170). The operator is then prompted for the sample thickness (line 180), and the program waits for the operator's signal to begin (lines 190 and 200).

Once the operator starts the test, the Model 236 is armed (line 210), and the unit is then triggered (line 220). The program then enters a loop (line 230) to test the sample with a total of eight readings. As part of each loop, the Model 705 command string is read from the DATA statements at the end of the program (line 240), the unit is then programmed to close the desired crosspoints (line 250), and the Model 236 is placed in operate. After a two-second delay for settling (line 270), a voltage reading is requested from the Model 236 and placed into an array (line 280). The Model 236 is placed in standby, and the crosspoints are then opened by reading the next command string (line 300) and then programming the Model 705 accordingly (line 310). The program then loops back for the next measurement (line 320).

Finally, the program computes both σ_A and σ_B (lines 340 and 350), and it then calculates and displays the average resistivity, σ_{AVG} (line 370). Note that the Model 705 command strings are located in DATA statements at the end of the program (lines 400-550)

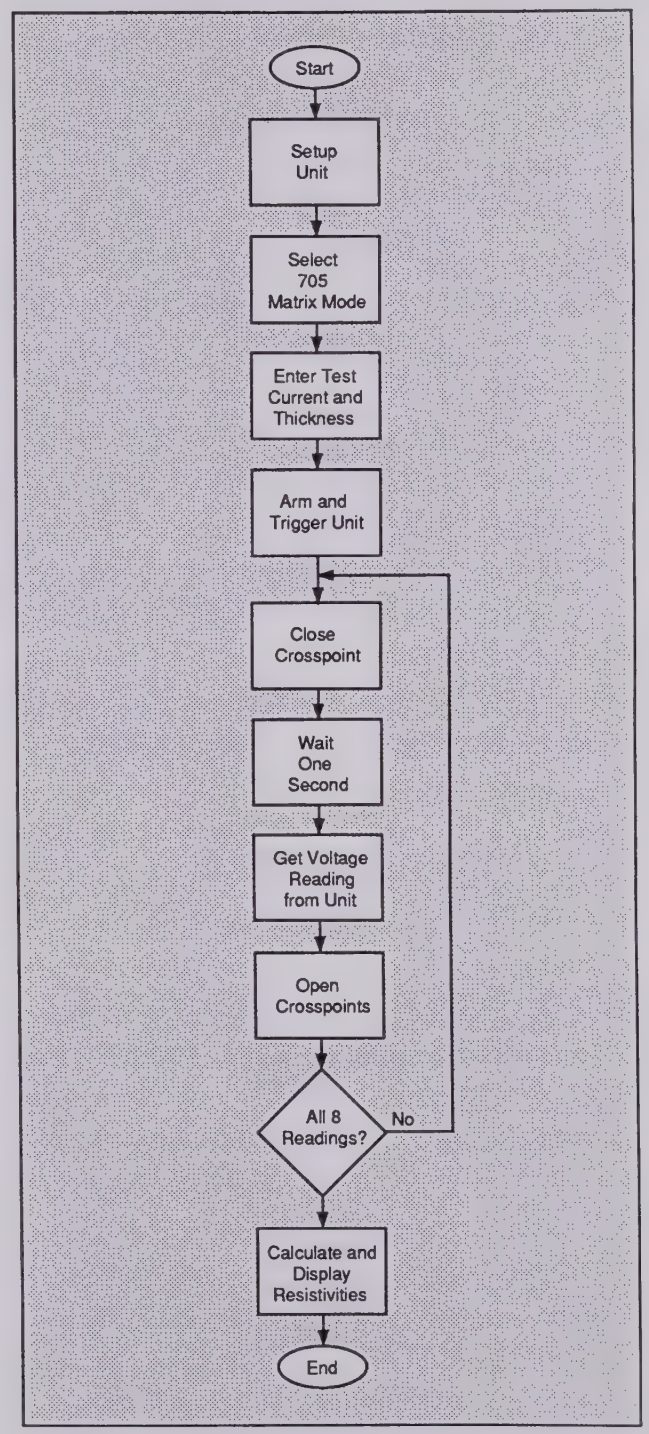


Figure 7-9. Program 21 Flowchart

CAUTION

When the Model 236/237 is in remote sensing, the output voltage will float up to maximum if the sense leads are open and the unit is in operate. To avoid possible switch card damage, always close the appropriate relays before placing the Model 236/237 in operate, and place the unit in standby before opening relays..

```
10    REM RESISTIVITY TEST PROGRAM REV 1.3 (Program 21)
20    CLEAR 7                          ! Clear Unit and scanner
30    OUTPUT KBD;CHR$(255);CHR$(75);   ! Clear screen
40    DIM V(8),Cmd$[25]                ! Dimension reading array,command string
50    REM ****** 236 setup (sources I,measures V) ************************
60    REMOTE 716                       ! Put 236 in remote
70    OUTPUT 716;"F1,0X"               ! Source I, DC mode
80    OUTPUT 716;"L10,0X"              ! 10V compliance, autorange measure
90    OUTPUT 716;"O1X"                 ! Remote sense
100   OUTPUT 716;"G4,2,0X"             ! Measure data,no prefix,DC data
110   OUTPUT 716;"T1,0,0,0X"           ! Continuous trigger on GET
120   OUTPUT 716;"S2Z0X"               ! Line cycle integration,suppress off
130   REM ****** 705 scanner setup (switches devices) ********************
140   REMOTE 717                       ! Put 705 in remote
150   OUTPUT 717;"A0X"                 ! Select matrix mode
160   INPUT "Enter test current",Itest       ! Input desired test current
170   OUTPUT 716;"B";Itest;",0,1000X"        ! Program 236 test current
180   INPUT "Enter sample thickness (cm)",Ts ! Input sample thickness
190   PRINT "Close lid, press CONT to begin"
200   PAUSE
210   OUTPUT 716;"R1X"                 ! Arm 236,
220   TRIGGER 716                      ! Trigger 236
230   FOR I=1 TO 8                     ! Loop for all eight measurements
240   READ Cmd$                        ! Read 705 command string
250   OUTPUT 717;Cmd$                  ! Close crosspoints
260   OUTPUT 716;"N1X"                 ! Put 236 in operate
270   WAIT 2                           ! Wait two seconds for settling
280   ENTER 716;V(I)                   ! Get voltage reading from 236
290   OUTPUT 716;"N000X"               ! Put 236 in standby,local sense
300   READ Cmd$                        ! Read 705 command string
310   OUTPUT 717;Cmd$                  ! Open crosspoints
320   NEXT I                           ! Loop back for next reading
330   OUTPUT 716;"N0X"                 ! Put 236 in standby
340   Pa=(1.1331*Ts*(V(2)+V(4)-V(1)-V(3)))/Itest ! Compute Pa
350   Pb=(1.1331*Ts*(V(6)+V(8)-V(5)-V(7)))/Itest ! Compute Pb
360   PRINT "Pa=";Pa                   ! Display Pa
370   PRINT "Pb=";Pb                   ! Display Pb
380   PRINT "Device average resistivity=";(Pa+Pb)/2  ! Display resistivity
```

```
390   REM DATA STATEMENTS CONTAINING 705 COMMAND STRINGS
400   DATA "C01:2C02:1C03:3C04:4X"
410   DATA "N01:2N02:1N03:3N04:4X"
420   DATA "C02:2C01:1C03:3C04:4X"
430   DATA "N02:2N01:1N03:3N04:4X"
440   DATA "C02:2C01:3C04:4C04:1X"
450   DATA "N02:2N01:3N04:4N04:1X"
460   DATA "C02:3C01:2C03:4C04:1X"
470   DATA "N02:3N01:2N03:4N04:1X"
480   DATA "C02:3C01:4C03:1C04:2X"
490   DATA "N02:3N01:4N03:1N04:2X"
500   DATA "C02:4C01:3C03:1C04:2X"
510   DATA "N02:4N01:3N03:1N04:2X"
520   DATA "C02:4C01:1C03:2C04:3X"
530   DATA "N02:4N01:1N03:2N04:3X"
540   DATA "C02:1C01:4C03:2C04:3X"
550   DATA "N02:1N01:4N03:2N04:3X"
560   END
```

7.4 SOURCE MEASURE UNIT MATRIX SWITCHING SYSTEM

The small matrix switching system discussed in the last paragraph has adequate capabilities for many applications. However, many applications call for a larger switching matrix. In the following paragraphs, we will discuss using Source Measure Units with a Model 7072 Semiconductor Matrix Card and a Model 707.

NOTE
Only Model 236 Units #1 and #2 are used for the applications example in this section in order to keep the program as simple as possible.

7.4.1 System Configuration

Figure 7-10 shows a typical configuration for the Source Measure Unit/matrix switching system. In addition to two Source Measure Units, the system also includes a Model 590 CV Analyzer, which can perform CV (capacitance-voltage) tests on semiconductors at 100kHz or 1MHz. Resulting CV curves can yield important information about semiconductors such as doping profile and depletion depth.

Switching for the system is performed by a Model 7072 Semiconductor Matrix Card installed within a Model 707 Switching Matrix. Each card is organized as an 8 × 12 matrix as shown.

The system can easily be expanded by adding more matrix cards in the mainframe. A total of six matrix cards can be installed in one mainframe, with easy internal row expansion (adding more columns to the matrix). For example, six cards would result in an 8 × 72 matrix, yielding 72-pin test capability with only one mainframe.

The test fixture used in this system is a Model 8007 Semiconductor Test Fixture, although a Model 8006 Test Fixture could be used as well. The Model 8007 is intended primarily for use with the Model 7072 card, and it includes 24-pin and 48-pin DIP sockets. The unit has 72-pin test capabilities, allowing it to support up to six Model 7072 cards.

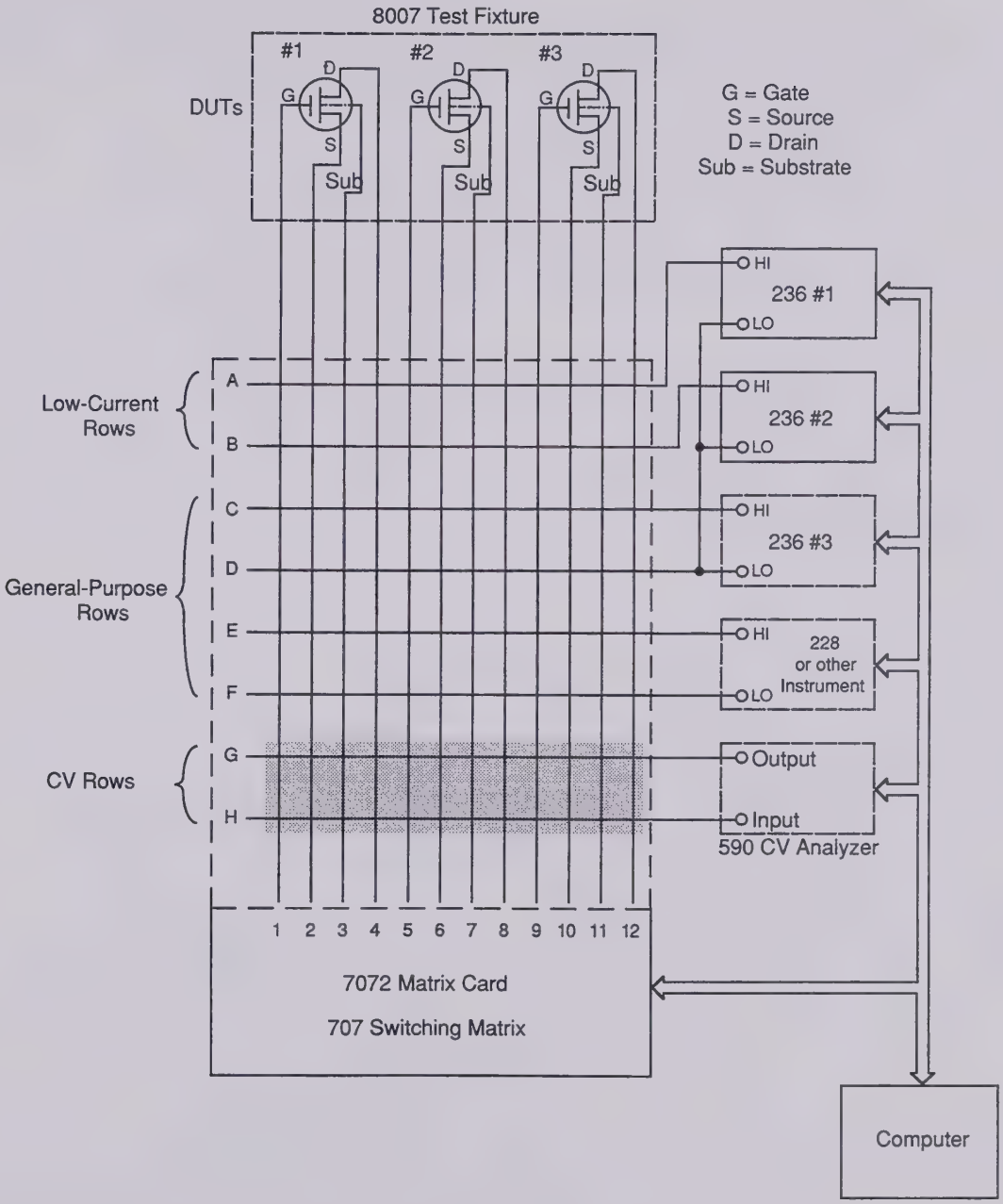


Figure 7-10. Source Measure Unit/CV System Configuration

7.4.2 Test Connections

Figure 7-11 details the test connections for the example in this paragraph. Note that local sensing is used for both Source Measure Units. The Source Measure Units are connected to the matrix card using Model 7078-TRX triax cables and insulated wire (LO to LO). Note that adapters must be used to connect the triax cable to the OUTPUT LO banana jack of Unit #2, as shown in Figure 7-12.

If suitable adapters are available, you could use banana plug patch cords for LO instead of triax cables.

WARNING

Connect interlock circuits before use. Connect the fixture ⏚ screw to safety earth ground using #18 AWG minimum wire before use. Turn off all power before connecting or disconnecting wires or cables.

The Model 8007 test fixture is connected to the matrix card using the Model 8007-MTC-3 Mass-Terminated Cable Assembly. A Model 8006 can be used instead; connections to Model 8006 triax connectors can be made using Model 7078-TRX triax cables.

7.4.3 Test Configuration

Figure 7-13 shows the test configuration for example Program 22 included in this paragraph. The test to be performed is a g_{fs} vs. V_{GS} test on three FET devices. Unit #1 sweeps V_{GS}, and Unit #2 sources V_{DS} and measures I_D. Note that the Model 590 CV Analyzer and Source Measure Unit #3 shown in Figure 7-11 are not used in this example in order to keep the program as simple as possible.

Refer to Section 4 for a complete description of how transconductance is computed.

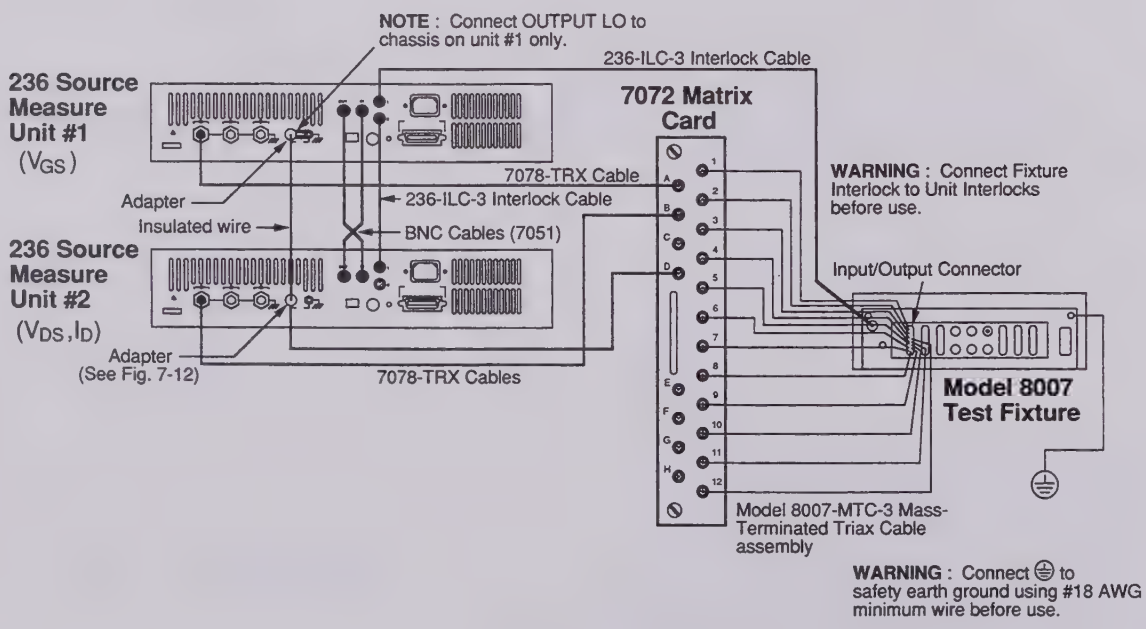

NOTE : Connect OUTPUT LO to chassis on unit #1 only.
236-ILC-3 Interlock Cable
236 Source Measure Unit #1 (VGS)
7072 Matrix Card
7078-TRX Cable
Adapter
236-ILC-3 Interlock Cable
Insulated wire
BNC Cables (7051)
236 Source Measure Unit #2 (VDS, ID)
Adapter (See Fig. 7-12)
7078-TRX Cables
WARNING : Connect Fixture Interlock to Unit Interlocks before use.
Input/Output Connector
Model 8007 Test Fixture
Model 8007-MTC-3 Mass-Terminated Triax Cable assembly
WARNING : Connect ⏚ to safety earth ground using #18 AWG minimum wire before use.

Figure 7-11. Connections for Example Program 22

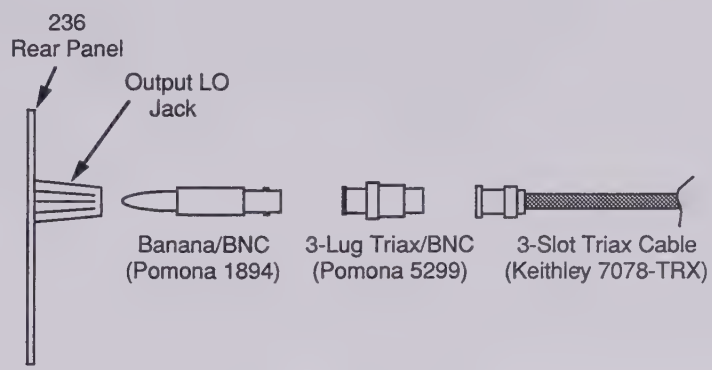


Figure 7-12. Connecting Triax Cables for OUTPUT LO Using Adapters

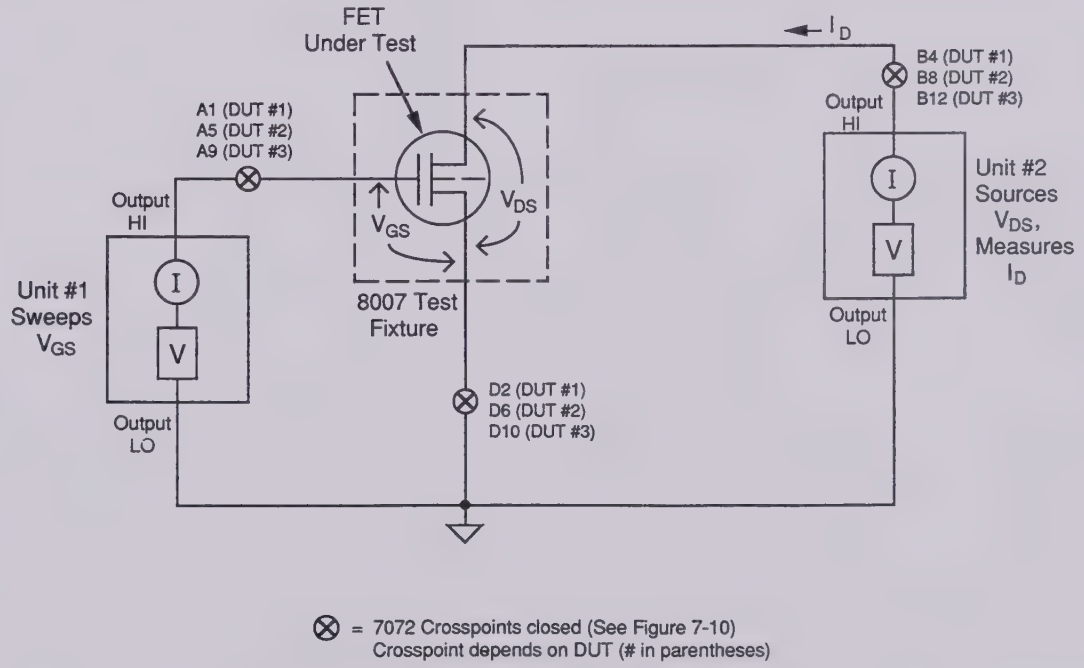


Figure 7-13. Program 22 Test Configuration

7.4.4 Measurement Considerations

Note that not all rows in the Model 7072 have the same capabilities: rows A and B are low-current rows (<1pA offset), rows C-F are general-purpose rows (<20pA offset), and rows G and H are designated as CV rows.

Similarly, not all rows have the same path isolation specifications. Rows A and B have the highest path isolation (>$10^{13}\Omega$), while rows C through H have a path isolation that is an order of magnitude lower (>$10^{12}\Omega$).

7.4.5 Example Program 22: Transconductance Test Using Switching Matrix

Use Program 22 below to generate a typical g_{fs} vs. V_{GS} plot for one of three FET devices as controlled by the switching matrix.

1. With the power off, connect both Source Measure Units and the switching mainframe to the IEEE-488 bus of the computer. Also install the Model 7072 card in slot 1 of the switching matrix.
2. Connect the units and the test fixture to the matrix card using suitable triax cables (see Figure 7-11 and Figure 7-13 for details on test connections and system configuration).
3. Turn on both Source Measure Units, and allow them to warm up for at least two hours for rated accuracy. Verify that the primary address of Unit #1 is set to 16 and that the primary address of Unit #2 is set to 17. Also turn on the Model 707 and verify that its primary address is set to 18.
4. Turn on the computer, then boot up BASIC.
5. Enter the lines from Program 22 below into the computer.
6. Place the device to be tested in the desired test fixture socket, then close the test fixture lid (the device should have characteristics similar to the 2N4392 used for other examples in this section).
7. RUN the program in the usual fashion, then choose the device to test when prompted to do so (1-3).
8. Continue the program to test all three devices. For the selected DUT, the program will step through V_{GS} values between –2V and 0V using 0.1V steps. At each increment, I_D will be measured using a fixed 10V V_{DS} value. Once data are collected, a plot of g_{fs} vs. V_{GS} for the selected device will be displayed on the computer CRT. To test the remaining two devices, rerun the program.
9. To return to BASIC from the graph of the DUT, press CONT.

7.4.6 Typical Program 22 Results

Figure 7-14 shows a typical g_{fs} vs. V_{GS} plot as generated by the example program.

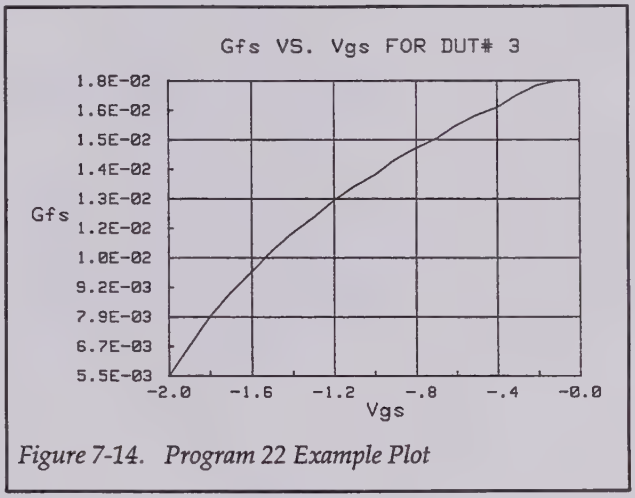


Figure 7-14. Program 22 Example Plot

7.4.7 Program 22 Description

Refer to the program listing below and the flowchart in Figure 7-15 for the following description of Program 22.

Initially, the data arrays are defined (lines 30-50) to hold 20 or 21 reading points. Note that two arrays are used in this program. The reading array will hold data obtained from the test instruments, while the plot array will hold computed g_{fs} and V_{GS} values to be plotted. Next, the command string is dimensioned (line 60).

After the instruments are returned to default conditions (line 70), Unit #1, which sweeps V_{GS}, is programmed as follows (lines 100-210):

- Source V, sweep mode
- 1mA compliance, 1mA range
- Local sense
- Source only data format, no prefix, sweep data output
- External trigger, one trigger per step, output trigger on end of measurement
- SRQ on sweep done
- Start V_{GS} voltage: –2V
- Stop V_{GS} voltage: 0V
- Step V_{GS} voltage: 0.1V
- Delay: 100msec
- Staircase sweep

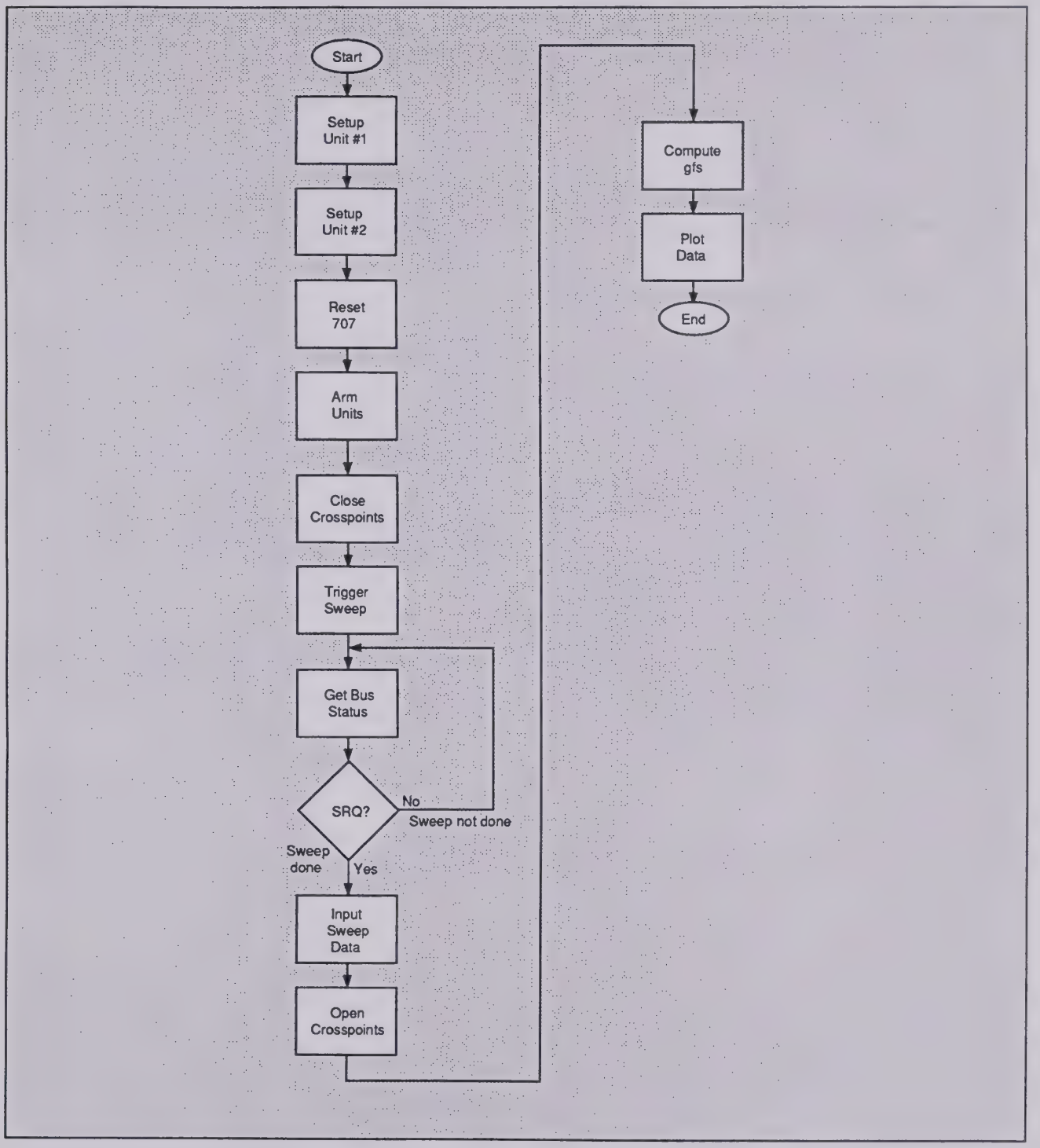


Figure 7-15. Program 22 Flowchart

Unit #2, which sources V_{DS} and measures I_D, is then configured in the following manner (lines 220-320):

- Source V, sweep mode
- Local sense
- 100mA compliance, autorange measure
- Measure only data format, no prefix, sweep data output
- External trigger, trigger source, output trigger on end of measurement
- Line cycle integration
- Constant sweep, 10V constant V_{DS} value, 21 points

Finally, the Model 707 is placed into remote and reset to ensure that all crosspoints are open (lines 340 and 350), and the DUT to be tested is selected (lines 360-440).

After operator signal (lines 450 and 460), both Source Measure Units are armed and placed into operate (lines 470-480), and the Model 707 is programmed to close the desired crosspoints (line 500). After a one-second delay for settling (line 510), Unit #2 is then triggered to start the sweep by using the immediate trigger command (line 520). Once Unit #2 is triggered, it sets V_{DS} to the programmed value, and it then triggers Unit #1 (using external triggering). Unit #1 then sets V_{GS} to the present value in its sweep list. Following the prescribed delay period, Unit #2 measures I_D and then goes on to the next point in the sweep. The process repeats until all points in the sweep have been taken.

While the sweep is being performed, the program waits in a loop for Unit #2 to generate an SRQ on sweep done (lines 530 and 540). Once the SRQ occurs, the data are read into the reading array (lines 560-590), and the Model 707 is programmed to open the presently-closed crosspoints (line 600). The Source Measure Units are then placed into standby (lines 610-620).

Next, we encounter the part of the program where the transconductance values are calculated (lines 670-720). First, the V_{GS} values are simply transferred from the (I,1) elements of the reading array to the (I,1) elements of the plot array (line 680). Next, ΔV_{GS} values are computed by subtracting the (I,1) values from the (I+1,1) values (line 690), and ΔI_D values are similarly computed by subtracting (I,2) values from (I+1,2) values (line 700). Finally, each transconductance value is computed from ΔI_D and ΔV_{GS} and stored in the corresponding element of the plot array (line 710).

The maximum and minimum transconductance values are then determined for Y axis scaling (lines 750-780), and the data are plotted with g_{fs} along the Y axis and V_{GS} along the X axis (lines 800-1110).

```
10    REM TRANSCONDUCTANCE-GATE VOLTAGE TEST PROGRAM REV. 1.3 (Program 22)
20    REM INCLUDES CONTROL OF 707 SWITCHING MATRIX
30    OPTION BASE 1                    ! First array subscript is 1
40    DIM Reading(21,2)                ! Dimension reading array (21 pts)
50    DIM Plot_array(20,2)             ! Dimension plot array (20 pts)
60    DIM Cmd$[25]                     ! Dimension command string
70    CLEAR 7                          ! Clear both Units
80    OUTPUT KBD;CHR$(255);CHR$(75);   ! Clear screen
90    REM ***** Unit 1 setup (sweeps Vgs) ****************************
100   REMOTE 716                       ! Put Unit 1 in remote
110   OUTPUT 716;"F0,1X"               ! Source V, sweep mode
120   OUTPUT 716;"L1E-3,7X"            ! 1mA compliance, 1mA range
130   OUTPUT 716;"O0X"                 ! Local sense
140   OUTPUT 716;"G1,2,1"              ! Output source,no prefix,sweep data
150   OUTPUT 716;"T3,1,4,0X"           ! External trigger,out trig end of measure
160   OUTPUT 716;"M2,X"                ! SRQ on sweep done
165   OUTPUT 716;"B0,0,0X"             ! Program 0 bias value
170   Vgstart=-2.0                     ! Define -2V start Vgs voltage
180   Vgstop=0                         ! Define 0V stop Vgs voltage
190   Vgstep=.1                        ! Define 0.1V step Vgs voltage
200   Dly=100                          ! Define 100msec Unit delay
210   OUTPUT 716;"Q1,";Vgstart;",";Vgstop;",";Vgstep;",0,";Dly;"X" ! Pgm swp
220   REM ***** Unit 2 setup (sources Vds, measures Id) ***************
230   REMOTE 717                       ! Put Unit 2 in remote
240   OUTPUT 717;"F0,1X"               ! Source V, sweep mode
250   OUTPUT 717;"O0X"                 ! Local sensing
260   OUTPUT 717;"L100E-3,0X"          ! 100mA compliance,autorange measure
270   OUTPUT 717;"G4,2,1X"             ! Measure,no prefix,sweep data
280   OUTPUT 717;"T3,1,4,0X"           ! Trig ext,start source,out end of meas
290   OUTPUT 717;"S2Z0X"               ! Line cycle integration,suppress off
295   OUTPUT 717;"B0,0,0X"             ! Program 0 bias value
300   Dly=100
310   Vds=10                           ! Define 10V Vds
320   OUTPUT 717;"Q0,";Vds;",0,";Dly;",21X" ! Constant sweep,21 points
330   REM ****** 707 setup (switches DUTs) ****************************
340   REMOTE 718                       ! Put 707 in remote
350   OUTPUT 718;"R0X"                 ! Reset 707
360   INPUT "Select DUT to test (1-3)",Dut ! Select DUT to test
370   SELECT Dut
380   CASE 1
390   Cmd$="A1,B4,D2"
400   CASE 2
410   Cmd$="A5,B8,D6"
420   CASE 3
430   Cmd$="A9,B12,D10"
440   END SELECT
450   PRINT "Close lid, press CONT to begin test"
460   PAUSE
470   OUTPUT 716;"R1N1X"               ! Arm Unit 1 trigger,turn on output
480   OUTPUT 717;"R1N1X"               ! Arm Unit 2 trigger,turn on output
490   PRINT "Generating sweep..."
500   OUTPUT 718;"C";Cmd$;"X"          ! Close crosspoints
```

```
510   WAIT 1                              ! Wait one second for settling
520   OUTPUT 716;"H0X"                    ! Trigger Unit 1 to start sweep
530   STATUS 7,7;Stat                     ! Get IEEE-488 bus status
540   IF NOT BIT(Stat,10) THEN 530        ! Wait for SRQ on sweep done
550   Stat=SPOLL(716)                     ! Serial poll Unit 1 to clear SRQ
560   FOR I=1 TO 21                       ! Loop for all 21 readings
570   ENTER 716;Reading(I,1)              ! Get Vgs data from Unit 1
580   ENTER 717;Reading(I,2)              ! Get Id data from Unit 2
590   NEXT I                              ! Loop back for next data point
600   OUTPUT 718;"N";Cmd$;"X"             ! Open crosspoints
610   OUTPUT 716;"N0X"                    ! Turn off Unit 1 output
620   OUTPUT 717;"N0X"                    ! Turn off Unit 2 output
630   PRINT "Press CONT to display graph of selected DUT"
640   PRINT "Press CONT while in graph to return to BASIC"
650   PAUSE
660   REM COMPUTE TRANSCONDUCTANCE AND STORE IN PLOT ARRAY
670   FOR I=1 TO 20                       ! Loop for all gfs points
680   Plot_array(I,1)=Reading(I,1)        ! Store Vgs in plot array
690   Delta_vgs=ABS(Reading(I+1,1)-Reading(I,1)) ! Compute delta Vgs
700   Delta_id=ABS(Reading(I+1,2)-Reading(I,2))  ! Compute delta Id
710   Plot_array(I,2)=Delta_id/Delta_vgs          ! Compute gfs
720   NEXT I                              ! Loop back for next point
730   Ymin=MAXREAL                        ! Find minimum and maximum gfs value
740   Ymax=-MAXREAL
750   FOR I=1 TO 20
760   IF Plot_array(I,2)<Ymin THEN Ymin=Plot_array(I,2)
770   IF Plot_array(I,2)>Ymax THEN Ymax=Plot_array(I,2)
780   NEXT I
790   OUTPUT KBD;CHR$(255);CHR$(75); ! Clear screen
800   GINIT                               ! Initialize graphics
810   PLOTTER IS CRT,"INTERNAL"           ! Define plot to CRT
820   GRAPHICS ON                         ! Turn on graphics
830   MOVE 40,90                          ! Title graph
840   LABEL "Gfs VS. Vgs FOR DUT#";Dut
850   MOVE 70,10                          ! Label X axis
860   LABEL "Vgs"
870   MOVE 0,53                           ! Label Y axis
880   LABEL "Gfs"
890   VIEWPORT 30,120,20,85               ! Define soft clip limits
900   WINDOW Vgstart,Vgstop,Ymin,Ymax ! Scale graph
910   Y1=(Ymax-Ymin)/10                   ! Compute Y axis increment
920   X1=(Vgstop-Vgstart)/10              ! Compute X axis increment
930   GRID 2*X1,2*Y1,Vgstart,Ymin         ! Draw grid
940   AXES X1,Y1,Vgstart,Ymin             ! Add some tick marks
950   FOR I=1 TO 20                       ! Plot data
960   PLOT Plot_array(I,1),Plot_array(I,2) ! Plot point
970   NEXT I
980   CSIZE 4                             ! Define character size
990   LORG 6                              ! Center characters
1000  CLIP OFF                            ! Turn off soft clipping
```

```
1010  FOR I=Vgstart TO Vgstop+.01*X1 STEP 2*X1 ! Number X axis
1020  MOVE I,Ymin-(Y1/4)
1030  LABEL USING "#,MD.D";I
1040  NEXT I
1050  FOR I=Ymin TO Ymax+.01*Y1 STEP Y1 ! Number Y axis
1060  MOVE Vgstart-(1.3*X1),I+(.3*Y1)
1070  LABEL USING "#,D.DE";I
1080  NEXT I
1090  PAUSE
1100  OUTPUT KBD;CHR$(255);CHR$(75); ! Clear alpha screen
1110  GRAPHICS OFF                   ! Clear graphics screen
1120  END
```

SECTION 8
Optimizing Measurement Speed

8.1 INTRODUCTION

Often, the speed of a measurement is of primary importance, especially where a large number of points or sweeps are involved. There are a number of factors which can affect the overall speed of any tests you make using a Source Measure Unit test system. In the following paragraphs, we will discuss the most important speed-related factors and give several example programs that demonstrate programming techniques for optimizing measurement speed.

8.2 FACTORS AFFECTING MEASUREMENT SPEED

The most important factors that will have an effect on overall speed are: integration rate, points per sweep, filtering, delay period, autoranging, and data format. Each of these factors is briefly discussed below.

8.2.1 Integration Rate

For fastest measurements, choose the S0 rate, which will result in the shortest integration period. Note, however, that resolution will be 4-1/2 digits, and noise will increase in comparison to the longer integration periods.

8.2.2 Points Per Sweep

The number of points per sweep will affect both the actual measurement time, as well as length of time it takes to process and transmit the sweep data over the IEEE-488 bus. For maximum throughput, program the unit for as few points per sweep as possible, while still fulfilling the test requirements.

8.2.3 Filtering

Adding filtering with the P command will increase measurement time because of the increased number of conversions averaged per reading. Some compromise between the amount of tolerable noise and measurement speed may be in order. If filtering is required to minimize noise, choose the minimum number of averaged conversions possible.

8.2.4 Delay Period

The programmed delay period between source and measurement will also affect the measurement speed. Note, however, that the delay period must be sufficiently long for the test circuit to settle, or inaccurate measurements will result. One way to determine the optimum delay period is to gradually decrease the delay from some arbitrarily-long value until a change in measurement values is noted. Increase the delay slightly from this point until the change is no longer present.

8.2.5 Autoranging

Autoranging will slow down a sweep in many cases because of the finite time period it takes for the instrument to change ranges during a sweep. For that reason, you should choose an appropriate manual range for both source and measure if measurement speed is of primary importance. Obviously, you must select a range that is high enough to handle the largest value to be sourced or measured. Also, some degradation in accuracy and resolution may occur when manual ranging is used.

8.2.6 Data Format

The data format affects the speed of data transfer over the IEEE-488 bus. The binary data format results in faster transmission than the ASCII data format because fewer bytes must be transmitted, and because less data processing is on the part of the instrument is required. For that reason, you should use the binary data format whenever possible if speed is of primary importance.

Figure 8-1 shows the HP binary data format used by the Model 236/237. The initial two bytes contain the count of the total bytes being sent, not including terminators. The repeated structure includes bytes for source, delay, measure, and time stamp values. Note that the data format should be programmed to eliminate those bytes not re-

quired for your particular application. In the example programs in this section, for example, only source and measure are required, so the instrument is programmed not to send delay and time values.

With the applications programs in this section, these binary values are placed into specific BASIC variables. These variables are also shown in Figure 8-1. Finally, note that the terminator bytes should be suppressed when using the binary data format by using the Y4 command. The controller should normally be programmed to terminate the input using some other method such as END or possibly by using the byte count information.

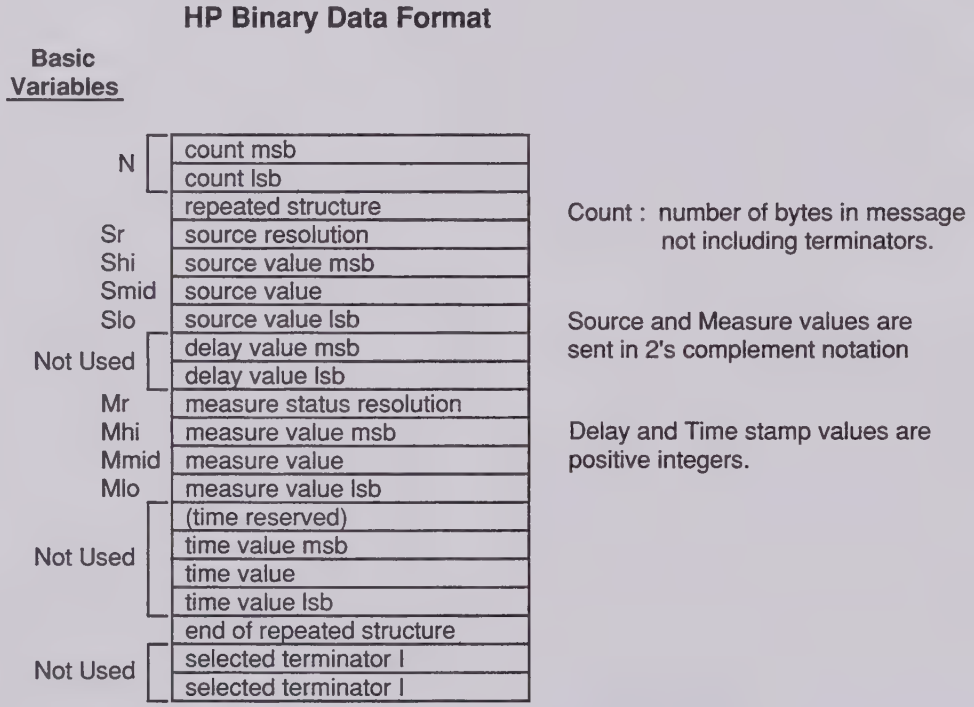
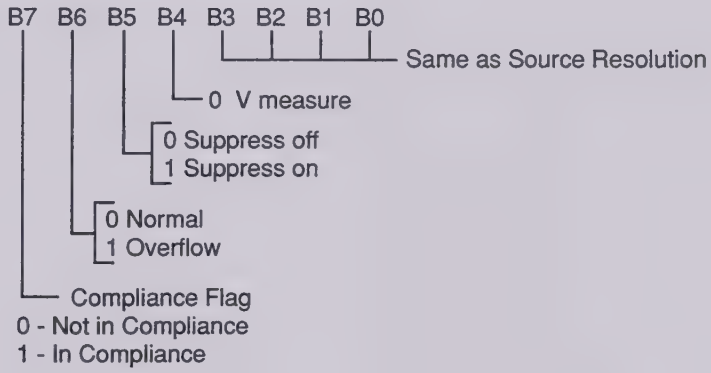


Figure 8-1. Binary Data Format

Source Resolution

Resolution ID	V source	I Source
0	10uv	10fa
1	100uv	100fa
2	1mv	1pa
3	10mv	10 pa
4	100mv	100 pa
5	(invalid)	1na
6	(invalid)	10na
7	(invalid)	100na
8	(invalid)	1ua
9	(invalid)	10ua

Measurement Status and Resolution



Binary Data Format (Cont.)

8.2.7 Controller Speed Considerations

The controller speed will affect key areas of overall test performance such as the data transfer itself or any number-crunching operations required. The HP controllers used for these applications examples use either DMA or fast-handshake transfer methods (when using TRANSFER), which should result in a substantial improvement in speed. However, because of the use of the interpretive BASIC language, the full speed increase potential may not be realized because of the relatively inefficient binary-to-decimal conversion process. However, those with compiled languages such as compiled BASIC or C should be able to take full advantage of increase in speed due to binary transfer.

8.3 DIODE TEST USING BINARY DATA FORMAT

Program 23 below demonstrates the basic techniques for using binary data transfer. This program is essentially the same as the diode test program (Program 3) presented in paragraph 2.6, with modifications to perform binary data transfer.

8.3.1 Test Configuration

Figure 8-2 shows the test configuration for the diode characterization test. The Model 236 is used to source the forward current, I_F, through the diode under test, and it also measures the forward voltage, V_F, across the device.

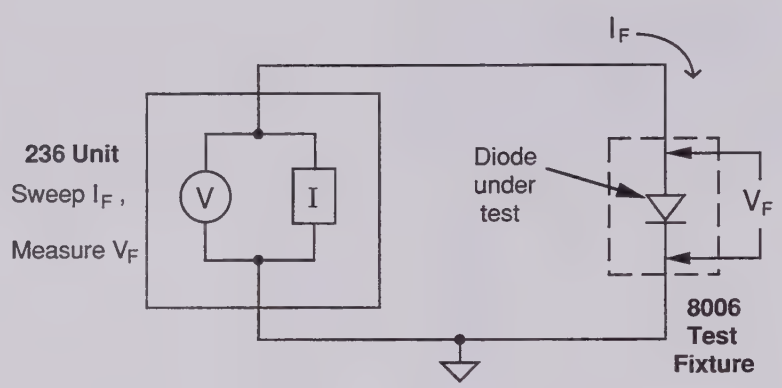


Figure 8-2. Diode Characterization Test Configuration

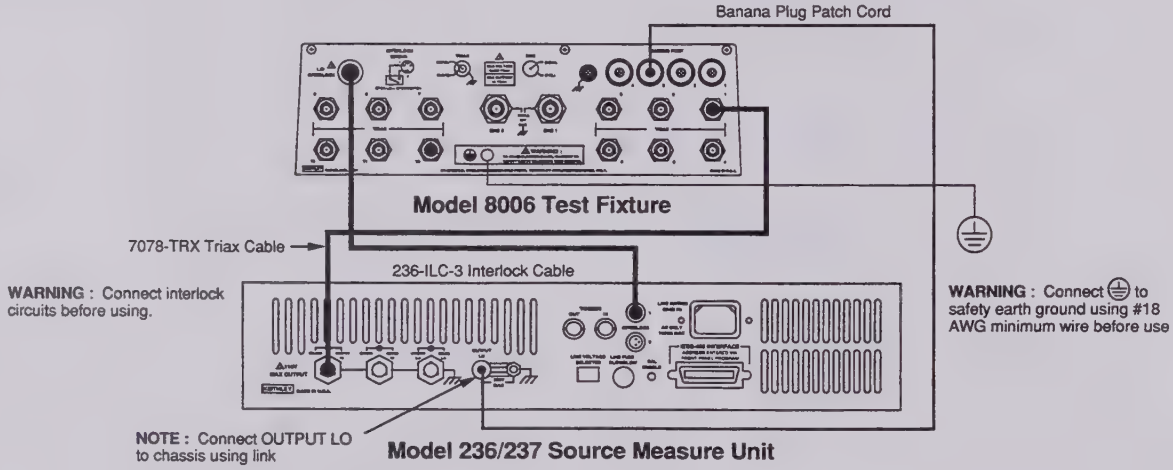

Banana Plug Patch Cord
Model 8006 Test Fixture
7078-TRX Triax Cable
236-ILC-3 Interlock Cable
WARNING : Connect interlock circuits before using.
WARNING : Connect ⏚ to safety earth ground using #18 AWG minimum wire before use
NOTE : Connect OUTPUT LO to chassis using link
Model 236/237 Source Measure Unit

Figure 8-3. Program 23 Test Connections

I_F is swept across the desired range of values, and V_F is measured at each current.

8.3.2 Test Connections

Figure 8-3 shows test connections for Program 23.

WARNING

Connect interlock circuits before use. Connect the fixture ⏚ screw to safety earth ground using #18 AWG minimum wire before use. Turn off all power before connecting or disconnecting wires or cables.

8.3.3 Example Program 23: Diode Characterization Using Binary Transfer

Program 23 below demonstrates the basic programming techniques for running the diode characterization test with binary transfer.

Follow the steps below to use this program.

1. With the power off, connect the Model 236 to the IEEE-488 interface of the computer.
2. Connect the test fixture to the Source Measure Unit using appropriate cables (see Figure 8-33).
3. Turn on the Model 236, and allow the unit to warm up for two hours for rated accuracy. Make sure the primary address of the unit is set to 16.

4. Turn on the computer, and boot up BASIC.
5. Enter the lines below into the computer.
6. Install a small-signal silicon diode such as a 1N914 or 1N4148 in the appropriate axial socket of the test fixture. Be certain that the jumpers are properly installed, then close the test fixture lid.
7. RUN the program in the usual manner. Enter the desired delay period when prompted to do so. Keep in mind that the delay period should be long enough to allow the device to settle properly before each measurement.
8. The computer will program the unit and run the diode test using currents between 0µA and 100µA in 1µA increments.
9. Once the sweep has been completed, you will be prompted to press CONT to generate a plot of the data. A simple V_F vs. I_F plot will then be displayed on the computer CRT.
10. To return to BASIC from the graph, press CONT.

8.3.4 Typical Program 23 Results

Figure 8-4 shows typical results obtained using example Program 3. These results are for a 1N4148 silicon diode.

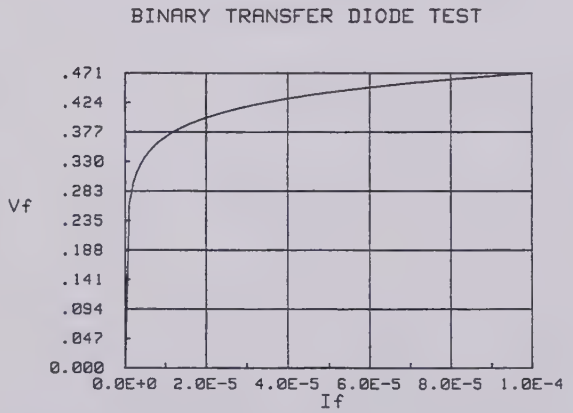


Figure 8-4. Example Program 23 Plot

8.3.5 Program 23 Description

For the following description, refer to the program listing and the flowchart shown in Figure 8-5.

Initially, the OPTION BASE statement is used to declare that all array subscripts begin with 1 rather than 0 (line 20), and the reading array is then dimensioned for 101 points with two readings each (line 30). The I/O path

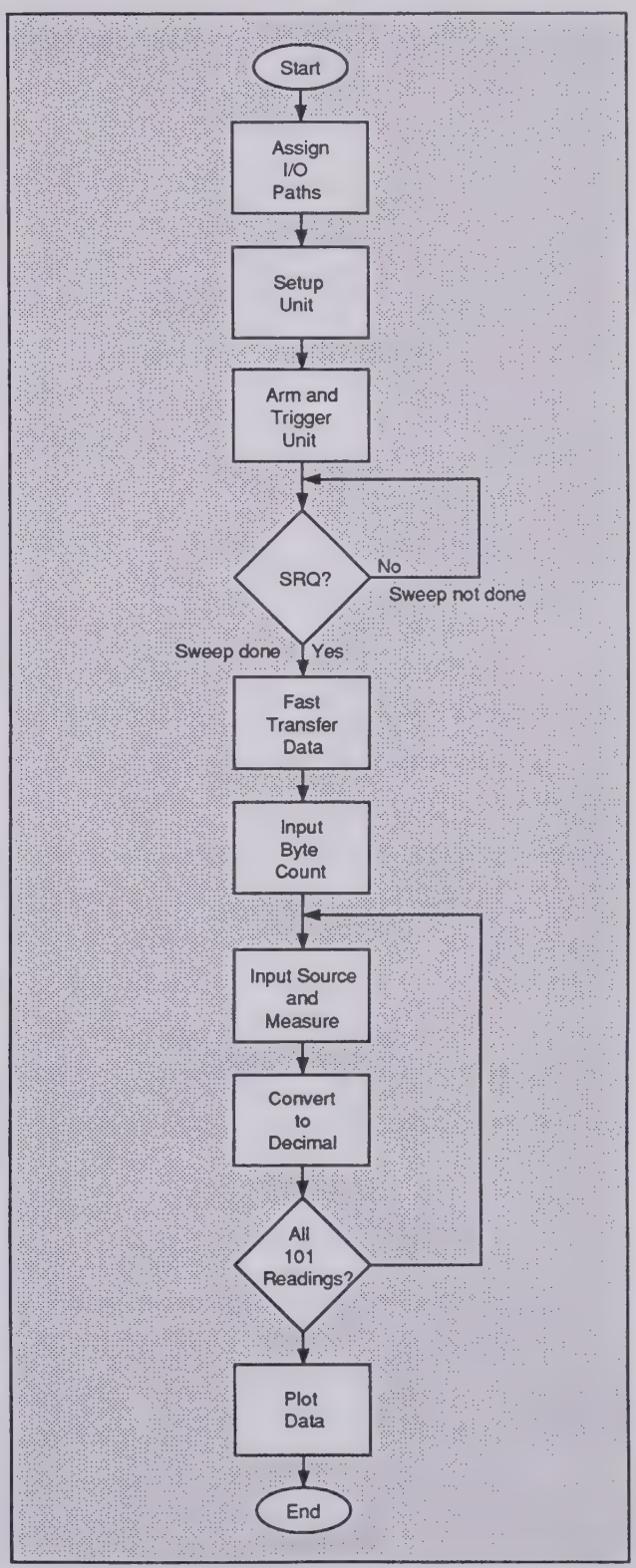


Figure 8-5. Program 23 Flowchart

name is then assigned to address 716 (line 40), and the transfer buffer is declared (line 50). Next, the Source Measure Unit is cleared and placed in remote (lines 60 and 70), and the unit is initialized as follows (lines 90-160):

- Source I, sweep mode
- Local sense, continuous trigger on GET
- 1V compliance, 1.1V range
- Source and measure binary data format, one sweep per talk
- SRQ on sweep done
- Suppress enabled
- Terminator off
- Shortest integration period
- Filter off
- Start current: 0μA
- Stop current: 100μA
- Step current: 1μA

After setup, the operator is prompted to input the desired delay (line 190), and sweep is then programmed using the 100μA source range (line 200). The operator is then prompted to signal the start of the test (lines 210 and 220). Following the operator signal, the trigger is armed (line 230), and the unit is placed into operate and triggered (lines 240 and 250). Following the trigger, the program enters a loop where it repeatedly checks the SRQ line on the bus to determine when the sweep is finished (lines 270 and 280).

When the unit finishes the sweep, it sets the SRQ line true, and the program falls out of the loop. The status byte is then read (line 290) to clear the SRQ, and the unit is placed in standby (line 300).

At this point, high-speed data transfer is performed by using the TRANSFER statement (line 310). Note that we are using the END and WAIT options with the TRANSFER statement. The END option dictates termination on EOI, while the WAIT option suspends program execution until transfer is complete. After statement execution, all bytes of the sweep data reside in the @Buf buffer of the computer.

The first two bytes requested after transfer are the byte count bytes, which are placed into variable N with the aid of the "W" image statement (line 320). Although this program does not use the byte count, the bytes still must be read from the buffer in order to update the buffer pointers. In many cases, you may find these bytes useful in determining how many bytes to input from the Source Measure Unit.

Next a loop is entered (line 330) to input and process all data bytes into the proper arrays. First, eight bytes are placed into variables using the appropriate image for byte values (line 340). These variables are defined as follows:

Sr (Source Resolution): This variable holds information on the the source resolution.

Shi (Source High): This variable contains the most-significant byte of the source value.

Smid (Source Middle Byte): This variable corresponds to the middle byte value of the source.

Slo (Source Low): This variable holds the least significant byte of the source value.

Mr (Measure Resolution): This variable contains the measurement resolution, compliance flag, and overflow information.

Mhi (Measure High): This variable includes the most-significant byte of the measure value.

Mmid (Measure middle value): This variable holds the middle byte of the measure value.

Mlo (Measure Low): This variable contains the least-significant byte of the measure value.

The important part of the binary-to-decimal conversion process in located in lines 340-390. First, the measure and source value high bytes are checked to see if they are negative, by testing bit 7 of the respective high bytes (lines 350 and 360). If either byte is negative, it is sign extended to properly convert negative values. Although there should be no negative values in this application, it is possible that some small negative offset or noise could occur.

Next, the measure resolution byte is masked so that its value represents only the resolution (line 370). The measure data is converted from binary to decimal (line 380), and the source value is converted using the same method (line 390).

After conversion, the source value, which is the forward current, is located in element (I,1) of the reading array,

and the measured voltage is in element (I,2) of the reading array. The minimum and maximum measured voltage values are then found (lines 410-460); these values are used to scale the Y axis of the plot. Plotting is performed (lines 510-800), with V_F along the Y axis, and I_F along the X axis.

```
10    REM BINARY TRANSFER DIODE CHARACTERIZATION PROGRAM REV. 1.3 (Program 23)
20    OPTION BASE 1                          ! First array subscript is 1
30    DIM Reading(101,2)                     ! Dimension reading array
40    ASSIGN @D236 TO 716                    ! Assign I/O path to 236
50    ASSIGN @Buf TO BUFFER [3000]           ! Assign I/O path to BUFFER
60    CLEAR 7                                ! Clear 236
70    REMOTE 716                             ! Put 236 in remote
80    OUTPUT KBD;CHR$(255);CHR$(75);         ! Clear screen
90    OUTPUT 716;"F1,1X"                     ! Source I, sweep mode
100   OUTPUT 716;"O0T1,0,0,0X"               ! Local sense, trigger on GET
110   OUTPUT 716;"L1,1X"                     ! 1V compliance, 1.1V range
120   OUTPUT 716;"G5,3,2X"                   ! Source,measure,binary data
130   OUTPUT 716;"M2,X"                      ! SRQ on sweep done
140   OUTPUT 716;"Z1X"                       ! Enable suppress
150   OUTPUT 716;"Y4S0P0X"                   ! Terminator off,fast rate,filter off
155   OUTPUT 716;"B0,0,0X"                   ! Program 0 bias value
160   Istart=0                               ! Define 0uA start current
170   Istop=1.00E-4                          ! Define 100uA stop current
180   Istep=1.0E-6                           ! Define 1uA step current
190   INPUT "Enter delay (msec)",Dly         ! Input delay value
200   OUTPUT 716;"Q1,";Istart;",";Istop;",";Istep;",0,";Dly;"X" !  Program sweep
210   PRINT "Close lid, press CONT to begin"
220   PAUSE                                  ! Wait to continue
230   OUTPUT 716;"R1X"                       ! Arm trigger
240   OUTPUT 716;"N1X"                       ! Turn on 236 output
250   TRIGGER 716                            ! Trigger 236 to start sweep
260   PRINT "Waiting for sweep to end"
270   STATUS 7,7;Stat                        ! Get IEEE-488 bus status
280   IF NOT BIT(Stat,10) THEN 270           ! Wait for SRQ on sweep done
290   Stat=SPOLL(716)                        ! Serial poll 236 to clear SRQ
300   OUTPUT 716;"N0X"                       ! Turn off 236 output
310   TRANSFER @D236 TO @Buf;END,WAIT        ! Transfer from 236 to computer
320   ENTER @Buf USING "%,W";N               ! Input reading count
330   FOR I=1 TO 101                         ! Loop for all readings
340   ENTER @Buf USING "%,B,B,B,B,B,B,B,B";Sr,Shi,Smid,Slo,Mr,Mhi,Mmid,Mlo
350   IF BIT(Mhi,7) THEN Mhi=BINEOR(Mhi,-256) ! Sign extend measure high byte
360   IF BIT(Shi,7) THEN Shi=BINEOR(Shi,-256) ! Sign extend source high byte
370   Mr=BINAND(Mr,15)                       ! Mask off range bits
380   Reading(I,2)=(65536*Mhi+256*Mmid+Mlo)*1.E-5*10^Mr ! Convert measure
390   Reading(I,1)=(65536*Shi+256*Smid+Slo)*1.E-14*10^Sr ! Convert source
400   NEXT I                                 ! Loop back for next reading
410   Ymin=MAXREAL                           ! Find minimum and maximum voltage
420   Ymax=-MAXREAL
430   FOR I=1 TO 101
440   IF Reading(I,2)<Ymin THEN Ymin=Reading(I,2)
450   IF Reading(I,2)>Ymax THEN Ymax=Reading(I,2)
460   NEXT I
470   PRINT "Press CONT to display graph"
480   PRINT "Press CONT while in graph to return to BASIC"
490   PAUSE
500   OUTPUT KBD;CHR$(255);CHR$(75);         ! Clear CRT
```

```
510   GINIT                                  ! Initialize graphics
520   PLOTTER IS CRT,"INTERNAL"              ! Define plot to CRT
530   GRAPHICS ON                            ! Turn on graphics
540   MOVE 30,95                             ! Title graph
550   LABEL "BINARY TRANSFER DIODE TEST"
560   MOVE 70,10                             ! Label X axis
570   LABEL "If"
580   MOVE 0,53                              ! Label Y axis
590   LABEL "Vf"
600   VIEWPORT 30,120,20,85                  ! Define soft clip limits
610   WINDOW Istart,Istop,Ymin,Ymax          ! Scale graph
620   X1=(Istop-Istart)/10                   ! Compute X axis increment
630   Y1=(Ymax-Ymin)/10                      ! Compute Y axis increment
640   GRID X1*2,Y1*2,Istart,Ymin             ! Draw grid
650   AXES X1,Y1,Istart,Ymin                 ! Add some tick marks
660   PLOT Reading(*)                        ! Plot data
670   CSIZE 4                                ! Define character size
680   LORG 6                                 ! Center characters
690   CLIP OFF                               ! Turn off soft clipping
700   FOR I=Istart TO Istop+.01*Istep STEP 2*X1 ! Number X axis
710   MOVE I,Ymin-(Y1/4)
720   LABEL USING "#,D.DESZ";I
730   NEXT I
740   FOR I=Ymin TO Ymax+.01*Y1 STEP Y1      ! Number Y axis
750   MOVE Istart-(1.3*X1),I+(.3*Y1)
760   LABEL USING "#,MDD.DDD";I
770   NEXT I
780   PAUSE
790   OUTPUT KBD;CHR$(255);CHR$(75);         ! Turn off alpha display
800   GRAPHICS OFF                           ! Turn off graphics display
810   END
```

8.4 COMMON-EMITTER CHARACTERISTICS USING BINARY DATA TRANSFER

Program 24 shown below is essentially the same program as discussed in Section 3 (Program 4) with modifications necessary to use binary data transfer. The following paragraphs give an overview of this program and how to run it.

8.4.1 Test Configuration

Figure 8-6 shows the test configuration for the common-emitter characteristic tests. Unit #1 sweeps I_B across the desired range, and Unit #2 sweeps V_{CE} and measures I_C. Note that an NPN transistor is shown as part of the test configuration. A small-signal NPN transistor with an approximate current gain of 500 (2N5089) is recommended for use with the test program below.

8.4.2 Test Connections

Figure 8-7 shows the test connections for Program 24.

WARNING
Connect interlock circuit before use. Connect fixture ⏚ screw to safety earth ground using #18 AWG minimum wire before use. Turn off all power before connecting or disconnecting wires or cables.

8.4.3 Measurement Considerations

The selected delay period should be sufficiently long to allow the device to completely settle before each measurement. Also, it may be necessary to change the programmed current values to optimize the tests for a particular device.

8.4.4 Program 24: Common-emitter Characteristics Using Binary Transfer

Program 24 below can be used to run common-emitter characteristic tests on small-signal NPN transistors using binary transfer to read data.

In order to run the program, follow the steps below.

1. With the power off, connect both Model 236 Source Measure Units to the IEEE-488 interface of the computer.
2. Connect the test fixture to both Source Measure Units using appropriate triax cables (see Figure 8-7).
3. Turn on both Model 236 Source Measure Units, and allow the units to warm up for two hours for rated

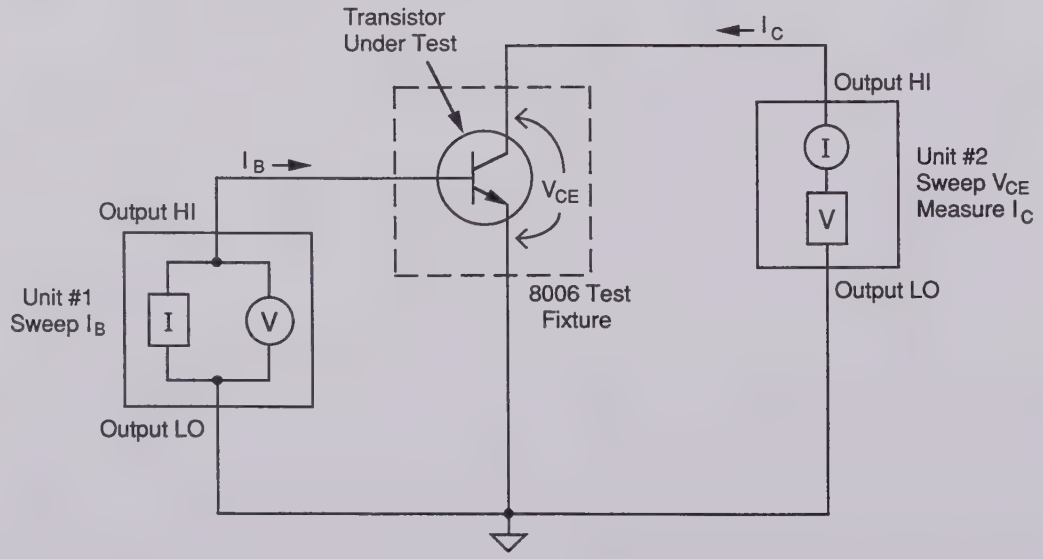


Figure 8-6. Test Configuration for Common-emitter Tests

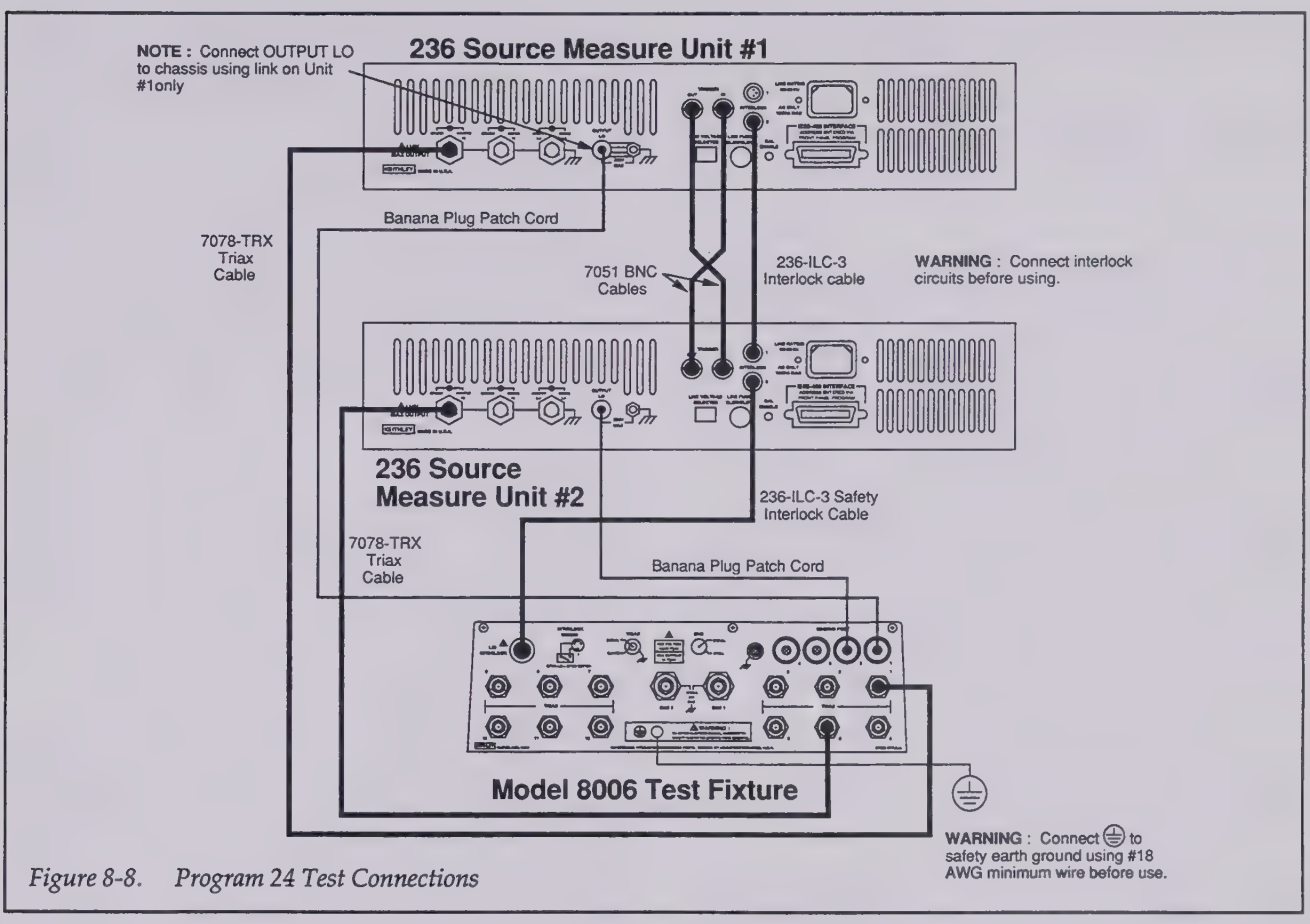

NOTE : Connect OUTPUT LO to chassis using link on Unit #1only
236 Source Measure Unit #1
Banana Plug Patch Cord
7078-TRX Triax Cable
7051 BNC Cables
236-ILC-3 Interlock cable
WARNING : Connect interlock circuits before using.
236 Source Measure Unit #2
236-ILC-3 Safety Interlock Cable
7078-TRX Triax Cable
Banana Plug Patch Cord
Model 8006 Test Fixture
WARNING : Connect ⏚ to safety earth ground using #18 AWG minimum wire before use.

Figure 8-8. Program 24 Test Connections

accuracy. Make sure the primary address of Unit #1 is set to 16 and that the primary address of Unit #2 is set to 17.

4. Turn on the computer, and boot up BASIC.
5. Enter the lines below into the computer.
6. Install a small-signal NPN silicon transistor such as a 2N5089 in the appropriate transistor socket of the test fixture. Be certain that the jumpers are properly installed, then close the test fixture lid.
7. RUN the program in the usual manner, and type in the desired delay period when prompted to do so. The computer will program both Source Measure Units and run the common-emitter characteristic test on the device. The base current will be swept between 10µA and 50µA in 10µA increments, and the value of V_{CE} will be swept between 0V and 10V in 0.1V increments.
8. Once the sweeps have been completed, you will be prompted to press CONT to generate a plot of the data. A simple I_C vs. V_{CE} plot will then be displayed on the computer CRT, with separate curves for each I_B value.
9. To return to BASIC from the graph, press CONT.

8.4.5 Typical Program 24 Results

Figure 8-9 shows typical results generated by example Program 4. A 2N5089 NPN silicon transistor was used to generate these test results.

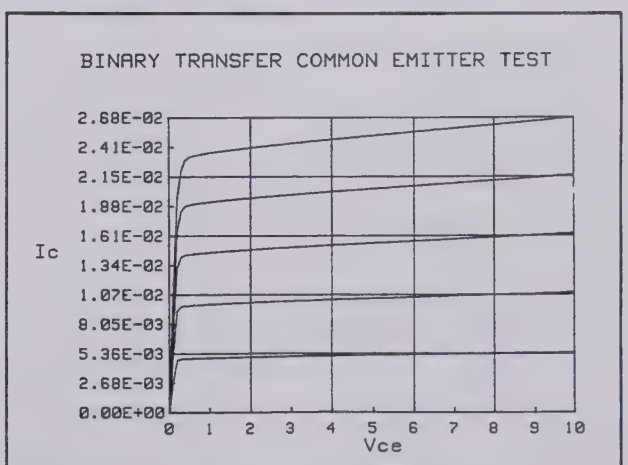


Figure 8-9. Example Plot for Test Program 24

8.4.6 Program 24 Description

For the following program description, refer to the program listing below and the flowchart shown in Figure 8-9.

Initially, the reading array is dimensioned (line 30) as a three-element array that will hold five sweeps of 101 points each, with two readings for each point. The I/O path and transfer buffers are then assigned (lines 40 and 50), and, both Source Measure Units are returned to default conditions by a DCL command (line 60). Unit #1, which sweeps I_B, is set up as follows (lines 90-180):

- Source I, sweep mode
- 1V compliance, 1.1V range
- Local sense
- Trigger on GET, one step per trigger, output trigger at end of delay
- Start I_B current: 10μA
- Stop I_B current: 50μA
- Step I_B current: 10μA
- Delay: user-programmed
- Staircase sweep (limits determined by start, stop, and step current)

Following Unit #1 setup, Unit #2, which sweeps V_{CE} and measures I_C, is programmed as follows (lines 200-320):

- Source V, sweep mode
- Local sensing
- 100mA compliance, 100mA range
- Source measure binary data format, complete sweep per talk
- SRQ on sweep done
- Suppress enabled
- Terminator off
- Fastest integration rate
- Filter off
- Trigger on external, one sweep per trigger
- Start V_{CE} voltage: 0V
- Stop V_{CE} voltage: 10V
- Step V_{CE} voltage: 0.1V
- Staircase sweep (limits determined by start, stop, and step voltage)

Once the two units are ready to go, both unit triggers are armed and the units are placed into operate (lines 350 and

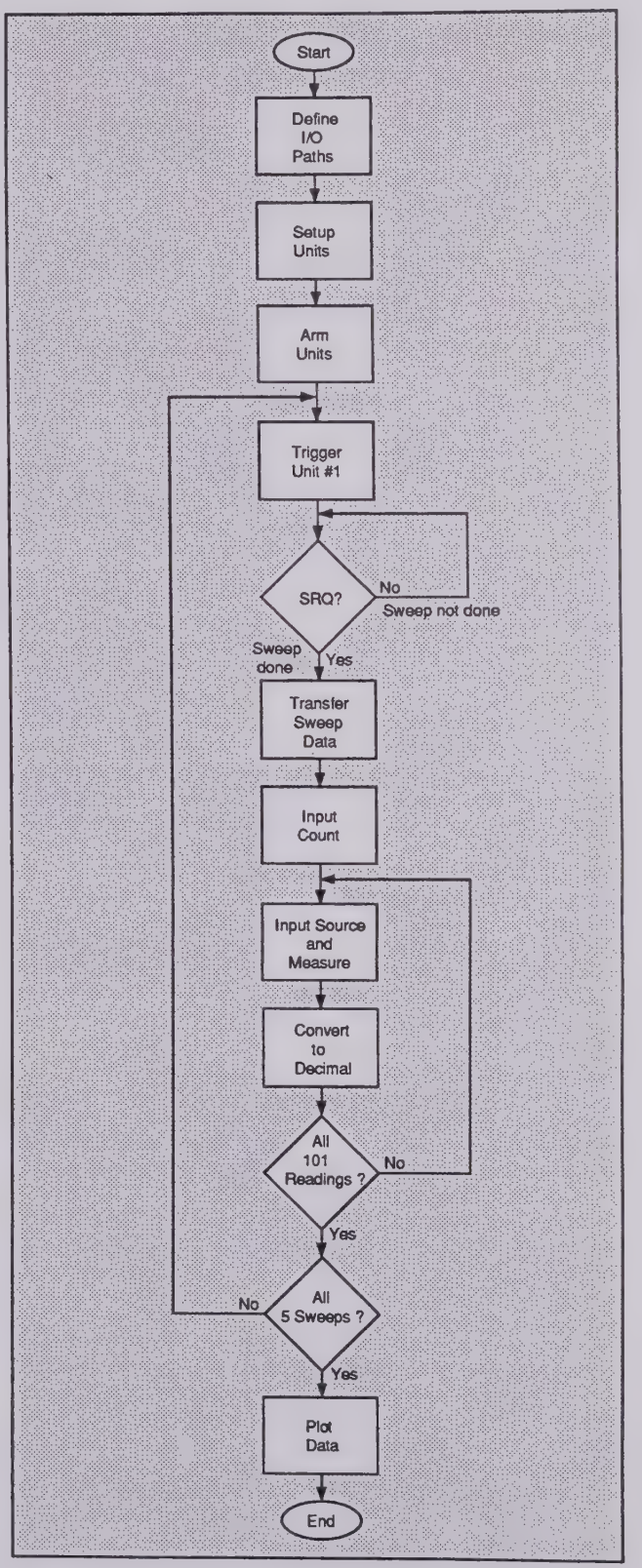


Figure 8-9. Program 24 Flowchart

360). The main programming loop is then entered to generate the five I_B curve sweeps (line 370).

To initiate each I_B curve sweep, Unit #1 is triggered over the bus by the IEEE GET command (line 390). This trigger causes Unit #1 to output the next programmed I_B current step. Following the programmed delay period, Unit #1 outputs a trigger pulse, which triggers Unit #2 to begin its sweep through all programmed V_{CE} values. At each V_{CE} value, Unit #2 measures I_C, and stores the data until the sweep is done.

In order to synchronize the program with each sweep, the program enters a loop to wait for Unit #2 to generate an SRQ (lines 400 and 410) when it has finished a sweep. Once each sweep has finished, Unit #2 is serial polled to clear the SRQ line (line 420).

At this point, the high-speed data transfer is performed by using the TRANSFER statement (line 430), again using the END and WAIT options with the TRANSFER statement. The first two bytes requested after transfer are the byte count bytes, which are placed into variable N with the aid of the "W" image statement (line 430). Once again, these bytes are not used by the program, but they still must be read from the buffer in order to update the buffer pointers.

Next a loop is entered (line 450) to input and process all data bytes into the proper arrays. First, eight bytes are placed into variables using the appropriate image for byte values (line 460). These variables are defined as follows:

Sr (Source Resolution): This variable contains information on the the source resolution.

Shi (Source High): This variable contains the most-significant byte of the source value.

Smid (Source Middle): This variable contains the middle byte of the source value.

Slo (Source Low): This variable holds the least significant byte of the source value.

Mr (Measure Resolution): This variable contains the measurement resolution, compliance flag, and overflow information.

Mhi (Measure High): This variable holds the most-significant byte of the measure value.

Mmid (Measure Middle Value): This variable contains the middle byte of the measure value.

Mlo (Measure Low): This variable contains the least-significant byte of the measure value.

After the information is transferred to the respective variables, bit 7 of Mhi and Shi are checked to determine if the values are negative. If so, the respective bytes are sign extended to convert to negative (lines 480 and 490). We are assuming that any negative values are the result of offsets or noise because all normal measured values are assumed to be positive.

The measure and source values are then converted to decimal (lines 500-510). After conversion, the source value is located in element (I,1) of the reading array, and the measured current is in element (I,2) of the reading array. The minimum and maximum measured collector current values are then found (lines 590-690), and data are then plotted (lines 680-1020).

```
10    REM BINARY TRANSFER COMMON EMITTER PROGRAM REV. 1.3 (Program 24)
20    OPTION BASE 1                    ! First array subscript is 1
30    DIM Reading(5,101,2)             ! Dimension reading array (5 swps,101 pts)
40    ASSIGN @D236 TO 717              ! Assign I/O path to Unit 2
50    ASSIGN @Buf TO BUFFER [2500]     ! Assign I/O path to BUFFER
60    CLEAR 7                          ! Clear both Units
70    OUTPUT KBD;CHR$(255);CHR$(75);   ! Clear screen
80    REM ***** Unit 1 setup (sweeps Ib) ****************************
90    REMOTE 716                       ! Put Unit 1 in remote
100   OUTPUT 716;"F1,1X"               ! Source I, sweep mode
110   OUTPUT 716;"L1,1X"               ! 1V compliance,1.1V range
120   OUTPUT 716;"O0X"                 ! Local sense
130   OUTPUT 716;"T1,1,2,0X"           ! GET trigger cycle,out trig end of delay
135   OUTPUT 716;"B0,0,0X"             ! Program 0 bias value
140   Istart=1.0E-5                    ! Define 10uA start Ib current
150   Istop=5.0E-5                     ! Define 50uA stop Ib current
160   Istep=1.0E-5                     ! Define 10uA step Ib current
170   INPUT "Enter delay (msec)",Dly   ! Input delay for both Units
180   OUTPUT 716;"Q1,";Istart;",";Istop;",";Istep;",0,";Dly;"X" ! Program sweep
190   REM ***** Unit 2 setup (sweeps Vce, measures Ic) ***************
200   REMOTE 717                       ! Put Unit 2 in remote
210   OUTPUT 717;"F0,1X"               ! Source V, sweep mode
220   OUTPUT 717;"O0X"                 ! Local sensing
230   OUTPUT 717;"L100E-3,9X"          ! 100mA compliance,100mA range
240   OUTPUT 717;"G5,3,2X"             ! Source,measure,binary,sweep data
250   OUTPUT 717;"M2,X"                ! SRQ on sweep done
255   OUTPUT 717;"B0,0,0X"             ! Program 0 bias value
260   OUTPUT 717;"Z1X"                 ! Enable suppress
270   OUTPUT 717;"T3,0,0,0X"           ! Trigger on external
280   OUTPUT 717;"Y4S0P0X"             ! Terminator off,fastest rate,no filtering
290   Vstart=0                         ! Define 0V start Vce
300   Vstop=10                         ! Define 10V stop Vce
310   Vstep=.1                         ! Define 0.1V step Vce
320   OUTPUT 717;"Q1,";Vstart;",";Vstop;",";Vstep;",0,";Dly;"X" ! Program sweep
330   PRINT "Close lid, press CONT to begin test"
340   PAUSE
350   OUTPUT 716;"R1N1X"               ! Arm Unit 1 trigger,turn on output
360   OUTPUT 717;"R1N1X"               ! Arm Unit 2 trigger, turn on output
370   FOR I=1 TO 5                     ! Loop for five Ib curves
380   PRINT "Generating sweep";I
390   TRIGGER 716                      ! Trigger Unit to start sweep
400   STATUS 7,7;Stat                  ! Get IEEE-488 bus status
410   IF NOT BIT(Stat,10) THEN 400     ! Wait for Unit 2 SRQ on sweep done
420   Stat=SPOLL(717)                  ! Serial poll Unit 2 to clear SRQ
430   TRANSFER @D236 TO @Buf;END,WAIT  ! Transfer from Unit 2 to computer
440   ENTER @Buf USING "%,W";N         ! Get count info
450   FOR J=1 TO 101                   ! Loop for all 101 readings
460   ENTER @Buf USING "%,B,B,B,B,B,B,B,B";Sr,Shi,Smid,Slo,Mr,Mhi,Mmid,Mlo
470   Mr=BINAND(Mr,15)                 ! Mask off range bits
480   IF BIT(Mhi,7) THEN Mhi=BINEOR(Mhi,-256) ! Sign extend measure high byte
490   IF BIT(Shi,7) THEN Shi=BINEOR(Shi,-256) ! Sign extend source high byte
500   Reading(I,J,2)=(65536*Mhi+256*Mmid+Mlo)*1.E-14*10^Mr ! Convert measure
```

```
510   Reading(I,J,1)=(65536*Shi+256*Smid+Slo)*1.E-5*10^Sr! Convert source value
520   NEXT J                          ! Loop back for next reading
530   NEXT I                          ! Loop back for next Ib value
540   OUTPUT 716;"N0X"                ! Turn off Unit 1 output
550   OUTPUT 717;"N0X"                ! Turn off Unit 2 output
560   PRINT "Press CONT to display graph"
570   PRINT "Press CONT while in graph to return to BASIC"
580   PAUSE
590   Ymin=MAXREAL                    ! Find minimum and maximum Ic value
600   Ymax=-MAXREAL
610   FOR I=1 TO 5
620   FOR J=1 TO 101
630   IF Reading(I,J,2)<Ymin THEN Ymin=Reading(I,J,2)
640   IF Reading(I,J,2)>Ymax THEN Ymax=Reading(I,J,2)
650   NEXT J
660   NEXT I
670   OUTPUT KBD;CHR$(255);CHR$(75); ! Clear screen
680   GINIT                           ! Initialize graphics
690   PLOTTER IS CRT,"INTERNAL"       ! Define plot to CRT
700   GRAPHICS ON                     ! Turn on graphics
710   MOVE 10,95                      ! Title graph
720   LABEL "BINARY TRANSFER COMMON EMITTER TEST"
730   MOVE 70,10                      ! Label X axis
740   LABEL "Vce"
750   MOVE 0,53                       ! Label Y axis
760   LABEL "Ic"
770   VIEWPORT 30,120,20,85           ! Define soft clip limits
780   WINDOW Vstart,Vstop,Ymin,Ymax   ! Scale graph
790   Y1=(Ymax-Ymin)/10               ! Compute Y axis increment
800   X1=(Vstop-Vstart)/10
810   GRID 2*X1,2*Y1,Vstart,Ymin      ! Draw grid
820   AXES X1,Y1,Vstart,Ymin          ! Add some tick marks
830   FOR I=1 TO 5                    ! Loop for all five curves
840   FOR J=1 TO 101                  ! Loop for all 101 points per curve
850   PLOT Reading(I,J,1),Reading(I,J,2) ! Plot point
860   NEXT J                          ! Plot next point
870   PENUP
880   NEXT I                          ! Plot next curve
890   CSIZE 4                         ! Define character size
900   LORG 6                          ! Center character
910   CLIP OFF                        ! Turn off soft clipping
920   FOR I=Vstart TO Vstop+.01*Vstep STEP X1 ! Number X axis
930   MOVE I,Ymin-(Y1/4)
940   LABEL USING "#,K";I
950   NEXT I
960   FOR I=Ymin TO Ymax+.01*Y1 STEP Y1 ! Number Y axis
970   MOVE Vstart-(1.3*X1),I+(.3*Y1)
980   LABEL USING "#,MD.DDE";I
990   NEXT I
1000  PAUSE
1010  OUTPUT KBD;CHR$(255);CHR$(75); ! Turn off alpha display
1020  GRAPHICS OFF                    ! Turn off graphics display
1030  END
```

8.5 SELF-BIAS THRESHOLD TEST WITH PLOTTING AND BINARY TRANSFER

The following paragraphs discuss the self-bias threshold test with added V_T vs. I_D plotting and binary transfer for maximum speed.

8.5.1 Self-bias Threshold Test Configuration

Figure 8-10 shows the general test configuration for the self-bias method of threshold voltage tests. Unit #1 sources the drain current, which is assumed to be the same as the source current, and it also measures the threshold voltage, V_T. Unit #2 sources V_{DS}. This arrangement allows very rapid threshold voltage measurement (milliseconds per reading) at very low currents, and it can be used with both enhancement-mode and depletion-mode FETs. Note that the high-impedance sensing circuits and the floating capabilities of the Models 236/237 are key characteristics that allow this special configuration to be used.

WARNING

When a Model 236/237 is programmed for remote sensing, hazardous voltage may be present on the SENSE and OUTPUT terminals when the unit is in operate regardless of the programmed voltage or current. To avoid a possible shock hazard, always turn off all power before connecting or disconnecting cables to the Source Measure Unit or the associated test fixture.

NOTE

Both V_{DS} and I_D must be programmed with reversed polarity because of the connection configuration used. For example, for an N-channel FET, both V_{DS} and I_D must be negative. These values will result in proper biasing of the DUT. Also, the sign of the measured V_T value will be reversed.

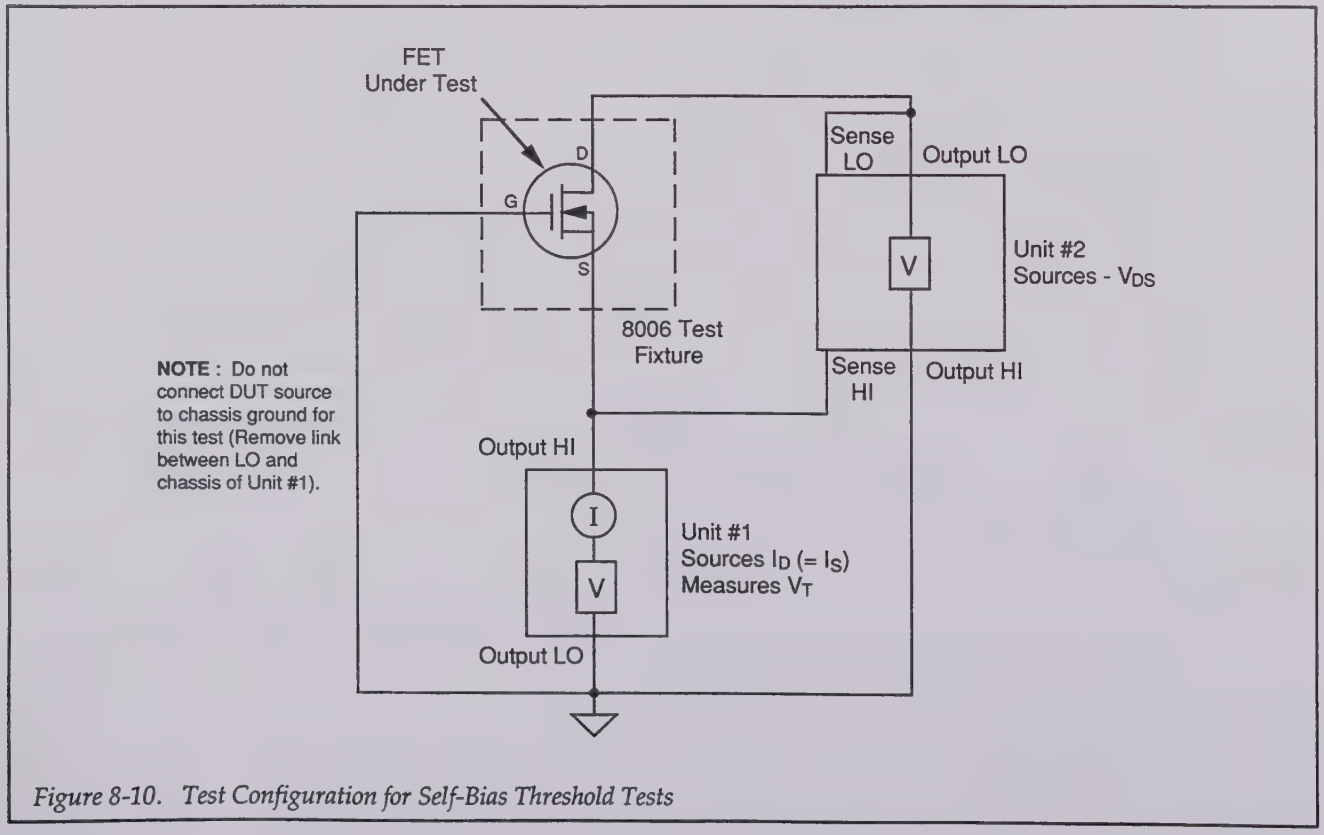


Figure 8-10. Test Configuration for Self-Bias Threshold Tests

8.5.2 Self-bias Method Measurement Considerations

There is a limit as to the maximum voltage that can appear between the sense and source leads of each Source Measure Unit. For that reason, the maximum threshold voltage that can be measured with this method is defined as follows:

$$V_{MAX} = 12 - 10\left(\frac{V_{DS}}{V_{FS}}\right)$$

Where V_{MAX} = maximum threshold voltage
V_{DS} = Unit 2 V_{DS} value
V_{FS} = full scale voltage range of Unit #2

For example, if V_{DS} has a value of 5V with the unit on the 11V measurement range, the maximum voltage is:

$$V_{MAX} = 12 - 10(5/11) = 7.45V$$

From this relationship, it can be seen that the voltage range of Unit #2 should be set as high as possible.

8.5.3 Program 25: Self-bias Threshold Voltage Tests with Plotting and Binary Data Transfer

Use Program 25 below to perform the self-bias threshold voltage test.

1. With the power off, connect both Source Measure Units to the IEEE-488 bus of the computer.
2. Connect both units to the test fixture with suitable triax cables using Figure 8-10 as a guide (refer to Figure 8-7 for physical test connections. Note that remote sensing connections are used for Unit #2, and that both OUTPUT LO and SENSE LO of Unit #2 are connected to the drain of the device under test. With this configuration, it will be necessary to program negative V_{DS} and I_D values in order to properly bias the DUT.
3. Turn on both units, and allow them to warm up for at least two hours for rated accuracy. Verify that the primary address of Unit #1 is set to 16; the primary address of Unit #2 should be set to 17.
4. Turn on the computer, then boot up BASIC.
5. Enter the lines from Program 25 below into the computer.
6. Place the desired N-channel (enhancement-mode or depletion-mode) FET in the appropriate transistor socket. Install the correct jumpers (using Figure 8-10 as a guide), then close the test fixture lid.
7. RUN the program in the usual fashion. The computer will program Unit #1 to step through I_D current values between –1μA and –100μA at –1μA increments, using a 0msec user delay for maximum speed and a fixed V_{DS} value of –10V.
8. After data are collected, the computer will display a graph of V_T vs. I_D, with both V_T and I_D sign adjusted for correct polarity.

8.5.4 Typical Program 25 Results

Figure 8-11 shows a typical plot generated by Program 25. The FET used for this example was a 2N4392 N-channel JFET.

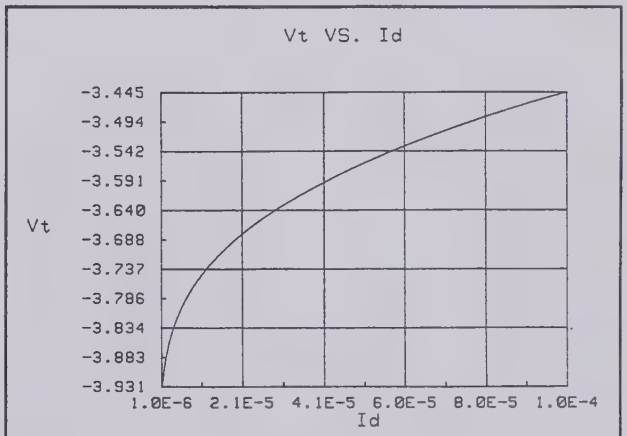


Figure 8-11. Typical Program 25 Results

8.5.5 Program 25 Description

Refer to the program listing below and the flowchart in Figure 8-12 for the following description of Program 25.

Initially, the data arrays and I/O paths are set up (lines 30-60), and then instruments are returned to default conditions (line 70). Next, Unit #1, which sources I_D and measures V_T, is programmed as follows (lines 100-220):

- Source I, sweep mode
- 10V compliance, 11V range
- Local sense
- Trigger on GET, continuous

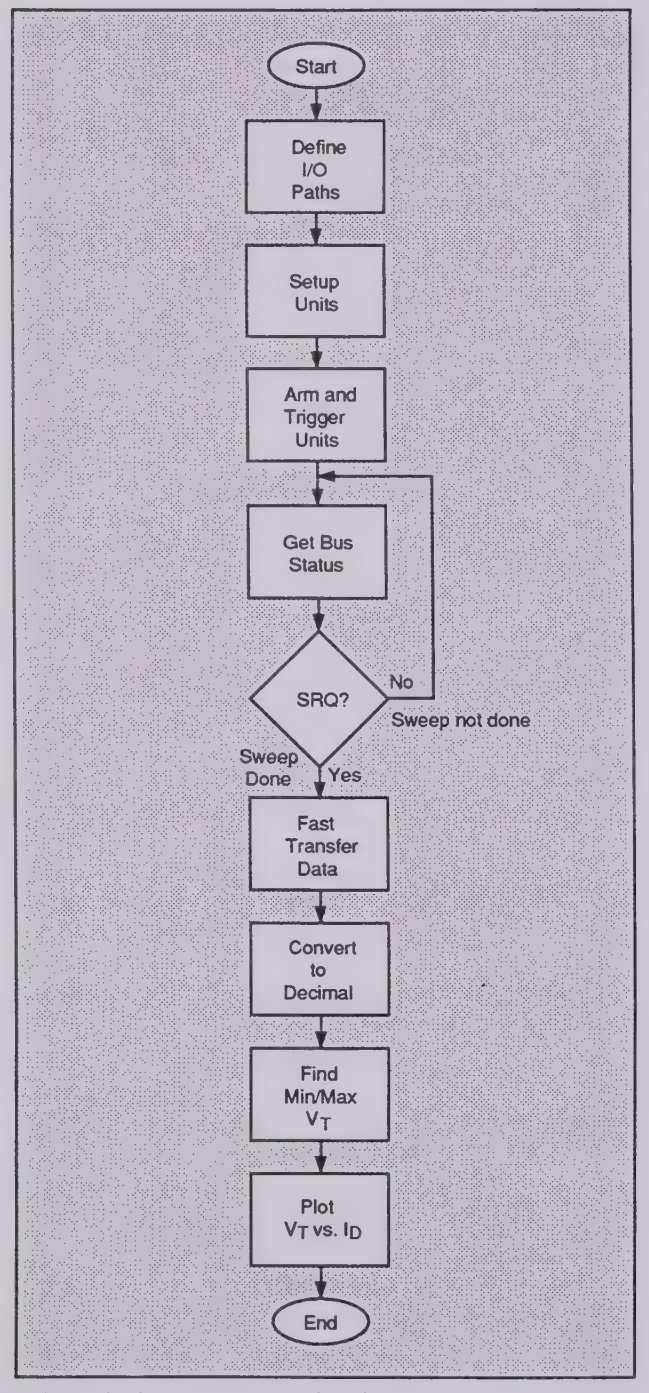


Figure 8-12. Program 25 Flowchart

- Source, measure data, no prefix or suffix, binary data
- SRQ on sweep done
- Terminator off, fastest integration rate, filter off
- Start I_D current: –1μA
- Stop I_D current: –100μA
- Step I_D current: –1μA
- Delay: 0msec

Next, Unit #2, which sources V_{DS} is then configured in the following manner (lines 240):

- Source V, dc mode
- Remote sensing
- 100mA compliance, 100mA range
- Trigger on GET, continuous
- –10V fixed V_{DS} value

After operator signal (lines 310 and 320), both Source Measure Units are armed and placed into operate (lines 330 and 340) and triggered (lines 350 and 360). The program then enters a loop to wait for Unit #1 to generate an SRQ (lines 370 and 370. After the SRQ, Unit #1 is serial polled to clear the SRQ (line 390), and both units are placed into standby (lines 400 and 410).

Unit #1 data is then transferred to the computer buffer (line 420), and the byte count is read from the buffer to update the buffer pointer (line 430). Next, the main input and conversion loop are set up (lines 440-510). Initially, all eight bytes of a reading are read from the buffer into BASIC variables (line 450), and the source and measure values are check to see if they are negative (lines 460 and 470). If so, the corresponding byte is sign extended to properly convert to a negative value. After this conversion, the measure resolution byte is masked to recover the resolution bits (line 480), and the source and measure values are converted to decimal and, at the same time, sign adjusted for correct polarity (lines 490 and 500).

After conversion, the maximum and minimum V_T values are determined (lines 520-570), and data is plotted as usual (lines 610-910).

8.5.6 Modifying Program 25

As written, the program tests for threshold voltages at 100 values of of I_D between –1μA and –100μA at –1μA increments (as pointed out previously, the programmed drain currents must be negative with an N-channel device because of the test configuration used). These values can be changed to the required values simply by modifying the corresponding variables in the program.

8.5.7 Self-bias Threshold Test Using Log Sweep

Often, the required sweep range is too large for a linear sweep. In such cases, a log sweep can be used. Program

26 is a modified version of Program 25 which will generate a plot of V_T vs. I_D using a range of I_D between 1nA and 100μA with 10 points per decade. Aside from the changes required to accommodate a log sweep, the other important changes include the use of line cycle integration as well as a 200msec delay period because of the low currents involved. Figure 8-13 shows an example plot generated by this program.

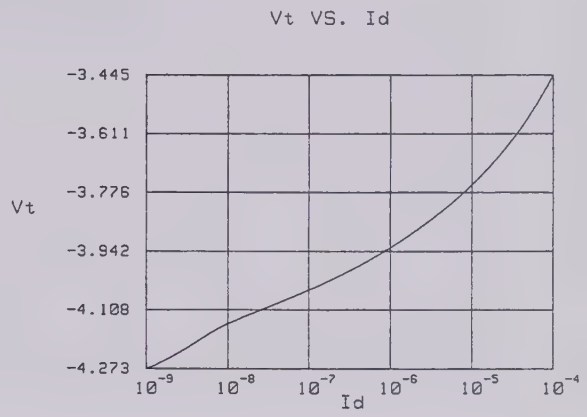


Figure 8-13. Program 26 Example Plot

```
10    REM SELF BIAS THRESHOLD VOLTAGE TEST PROGRAM REV. 1.3 (Program 25)
20    REM INCLUDES BINARY TRANSFER AND PLOTTING OF Vt VS. Id
30    OPTION BASE 1                    ! First array subscript is 1
40    DIM Reading(100,2)               ! Dimension reading array
50    ASSIGN @D236 TO 716              ! Assign I/O path to 236
60    ASSIGN @Buf TO BUFFER [3000]     ! Assign I/O path to BUFFER
70    CLEAR 7                          ! Clear both Units
80    OUTPUT KBD;CHR$(255);CHR$(75);   ! Clear screen
90    REM ***** Unit 1 setup (sources -Id, measures -Vt) ***************
100   REMOTE 716                       ! Put Unit 1 in remote
110   OUTPUT 716;"F1,1X"               ! Source I, sweep mode
120   OUTPUT 716;"L10,2X"              ! 10V compliance, 11V range
130   OUTPUT 716;"O0Z0X"               ! Local sense,suppress off
140   OUTPUT 716;"T1,0,0,0X"           ! GET trigger,continuous
150   OUTPUT 716;"G5,3,2X"             ! Source,measure,binary data
160   OUTPUT 716;"M2,X"                ! SRQ on sweep done
170   OUTPUT 716;"Y4S0P0X"             ! Terminator off,fast rate,filter off
175   OUTPUT 716;"B0,0,0X"             ! Program 0 bias value
180   Istart=-1.0E-6                   ! Define -1uA start current
190   Istop=-1.00E-4                   ! Define -100uA stop current
200   Istep=-1.0E-6                    ! Define -1uA step current
210   Dly=0                            ! Define 0 sec Unit delay
220   OUTPUT 716;"Q1,";Istart;",";Istop;",";Istep;",0,";Dly;"X" ! Pgm swp
230   REM ***** Unit 2 setup (sources -Vds) ****************************
240   REMOTE 717                       ! Put Unit 2 in remote
250   OUTPUT 717;"F0,0X"               ! Source V, DC mode
260   OUTPUT 717;"O1X"                 ! Remote sensing
270   OUTPUT 717;"L100E-3,9X"          ! 100mA compliance,100mA range
280   OUTPUT 717;"T1,0,0,0X"           ! Get trigger, continuous
290   Vds=-10                          ! Define -10V Vds value
300   OUTPUT 717 ;"B";Vds;",3,";Dly;"X"  ! Program DC, 110V range,delay
310   PRINT "Close lid, press CONT to begin test"
320   PAUSE
330   OUTPUT 716;"R1N1X"               ! Arm Unit 1 trigger,turn on output
340   OUTPUT 717;"R1N1X"               ! Arm Unit 2 trigger,turn on output
350   TRIGGER 717                      ! Trigger Unit 2
360   TRIGGER 716                      ! Trigger Unit 1
370   STATUS 7,7;Stat                  ! Get bus status
380   IF NOT BIT(Stat,10) THEN 370     ! Wait for SRQ
390   Stat=SPOLL(716)                  ! Serial poll Unit 1 to clear SRQ
400   OUTPUT 716;"N0X"                 ! Turn off Unit 1 output
410   OUTPUT 717;"N0O0X"               ! Turn off Unit 2 output,local sense
420   TRANSFER @D236 TO @Buf;END,WAIT ! Fast transfer data to computer
430   ENTER @Buf USING "%,W";N         ! Input reading count
440   FOR I=1 TO 100                   ! Loop for all readings
450   ENTER @Buf USING "%,B,B,B,B,B,B,B,B";Sr,Shi,Smid,Slo,Mr,Mhi,Mmid,Mlo
460   IF BIT(Mhi,7) THEN Mhi=BINEOR(Mhi,-256) ! Sign extend measure high byte
470   IF BIT(Shi,7) THEN Shi=BINEOR(Shi,-256) ! sign extend source high byte
480   Mr=BINAND(Mr,15)                 ! Mask off range bits
490   Reading(I,2)=-(65536*Mhi+256*Mmid+Mlo)*1.E-5*10^Mr  ! Convert measure
500   Reading(I,1)=-(65536*Shi+256*Smid+Slo)*1.E-14*10^Sr ! Convert source
```

```
510   NEXT I                              ! Loop back for next reading
520   Ymin=MAXREAL                        ! Find minimum and maximum Vt
530   Ymax=-MAXREAL
540   FOR I=1 TO 100
550   IF Reading(I,2)<Ymin THEN Ymin=Reading(I,2)
560   IF Reading(I,2)>Ymax THEN Ymax=Reading(I,2)
570   NEXT I
580   PRINT "Press CONT to display graph"
590   PRINT "Press CONT while in graph to return to BASIC"
600   PAUSE
610   OUTPUT KBD;CHR$(255);CHR$(75); ! Clear CRT
620   GINIT                               ! Initialize graphics
630   PLOTTER IS CRT,"INTERNAL"           ! Define plot to CRT
640   GRAPHICS ON                         ! Turn on graphics
650   MOVE 55,95                          ! Title graph
660   LABEL "Vt VS. Id"
670   MOVE 70,10                          ! Label X axis
680   LABEL "Id"
690   MOVE 0,53                           ! Label Y axis
700   LABEL "Vt"
710   VIEWPORT 30,120,20,85               ! Define soft clip limits
720   WINDOW -Istart,-Istop,Ymin,Ymax ! Scale graph
730   X1=(Istart-Istop)/10                ! Compute X axis increment
740   Y1=(Ymax-Ymin)/10                   ! Compute Y axis increment
750   GRID X1*2,Y1*2,-Istart,Ymin         ! Draw grid
760   AXES X1,Y1,-Istart,Ymin             ! Add some tick marks
770   PLOT Reading(*)                     ! Plot data
780   CSIZE 4                             ! Define character size
790   LORG 6                              ! Center characters
800   CLIP OFF                            ! Turn off soft clipping
810   FOR I=-Istart TO -Istop+.01*(-Istep) STEP 2*X1  ! Number X axis
820   MOVE I,Ymin-(Y1/4)
830   LABEL USING "#,D.DESZ";I
840   NEXT I
850   FOR I=Ymin TO Ymax+.01*Y1 STEP Y1 ! number Y axis
860   MOVE -Istart-(1.3*X1),I+(.3*Y1)
870   LABEL USING "#,MDD.DDD";I
880   NEXT I
890   PAUSE
900   OUTPUT KBD;CHR$(255);CHR$(75); ! Turn off alpha display
910   GRAPHICS OFF                        ! Turn off graphics display
920   END
```

```
10    REM LOG SWEEP SELF BIAS THRESHOLD VOLTAGE PROGRAM REV. 1.3 (Program 26)
20    REM INCLUDES BINARY TRANSFER AND PLOTTING OF Vt VS. Id
30    OPTION BASE 1                    ! First array subscript is 1
40    DIM Reading(51,2)                ! Dimension reading array
50    ASSIGN @D236 TO 716              ! Assign I/O path to 236
60    ASSIGN @Buf TO BUFFER [3000]     ! Assign I/O path to BUFFER
70    CLEAR 7                          ! Clear both Units
80    OUTPUT KBD;CHR$(255);CHR$(75);   ! Clear screen
90    REM ***** Unit 1 setup (sources -Id, measures -Vt) ***************
100   REMOTE 716                       ! Put Unit 1 in remote
110   OUTPUT 716;"F1,1X"               ! Source I, sweep mode
120   OUTPUT 716;"L10,2X"              ! 10V compliance, 11V range
130   OUTPUT 716;"O0Z0X"               ! Local sense,suppress off
140   OUTPUT 716;"T1,0,0,0X"           ! GET trigger,continuous
150   OUTPUT 716;"G5,3,2X"             ! Source,measure,binary data
160   OUTPUT 716;"M2,X"                ! SRQ on sweep done
170   OUTPUT 716;"Y4S2P0X"             ! Terminator off,line cycle,filter off
175   OUTPUT 716;"B0,0,0X"             ! Program 0 bias value
180   Istart=-1.0E-9                   ! Define -1nA start current
190   Istop=-1.00E-4                   ! Define -100uA stop current
200   Points=1                         ! 10 points per decade
210   Dly=200                          ! Define 200msec Unit delay
220   OUTPUT 716;"Q2,";Istart;",";Istop;",";Points;",0,";Dly;"X" ! Pgm LOG swp
230   REM ***** Unit 2 setup (sources -Vds) ****************************
240   REMOTE 717                       ! Put Unit 2 in remote
250   OUTPUT 717;"F0,0X"               ! Source V, DC mode
260   OUTPUT 717;"O1X"                 ! Remote sensing
270   OUTPUT 717;"L100E-3,9X"          ! 100mA compliance,100mA range
280   OUTPUT 717;"T1,0,0,0X"           ! Get trigger, continuous
290   Vds=-10                          ! Define -10V Vds value
300   OUTPUT 717 ;"B";Vds;",3,";Dly;"X"  ! Program DC, 110V range,delay
310   PRINT "Close lid, press CONT to begin test"
320   PAUSE
330   OUTPUT 716;"R1N1X"               ! Arm Unit 1 trigger,turn on output
340   OUTPUT 717;"R1N1X"               ! Arm Unit 2 trigger,turn on output
350   TRIGGER 717                      ! Trigger Unit 2
360   TRIGGER 716                      ! Trigger Unit 1
370   STATUS 7,7;Stat                  ! Get bus status
380   IF NOT BIT(Stat,10) THEN 370     ! Wait for SRQ
390   Stat=SPOLL(716)                  ! Serial poll Unit 1 to clear SRQ
400   OUTPUT 716;"N0X"                 ! Turn off Unit 1 output
410   OUTPUT 717;"N000X"               ! Turn off Unit 2 output,local sense
420   TRANSFER @D236 TO @Buf;END,WAIT ! Fast transfer data to computer
430   ENTER @Buf USING "%,W";N         ! Input reading count
440   FOR I=1 TO 51                    ! Loop for all readings
450   ENTER @Buf USING "%,B,B,B,B,B,B,B,B";Sr,Shi,Smid,Slo,Mr,Mhi,Mmid,Mlo
460   IF BIT(Mhi,7) THEN Mhi=BINEOR(Mhi,-256) ! Sign extend measure high byte
470   IF BIT(Shi,7) THEN Shi=BINEOR(Shi,-256) ! sign extend source high byte
480   Mr=BINAND(Mr,15)                 ! Mask off range bits
490   Reading(I,2)=-(65536*Mhi+256*Mmid+Mlo)*1.E-5*10^Mr  ! Convert measure
500   Reading(I,1)=-(65536*Shi+256*Smid+Slo)*1.E-14*10^Sr ! Convert source
```

```
510   NEXT I                              ! Loop back for next reading
520   Ymin=MAXREAL                        ! Find minimum and maximum Vt
530   Ymax=-MAXREAL
540   FOR I=1 TO 51
550   IF Reading(I,2)<Ymin THEN Ymin=Reading(I,2)
560   IF Reading(I,2)>Ymax THEN Ymax=Reading(I,2)
570   NEXT I
580   FOR I=1 TO 51                       ! Find LOG of source data
590   Reading(I,1)=LGT(Reading(I,1))
600   NEXT I
610   Xmin=LGT(ABS(Istart))               ! Find LOG of min X axis value
620   Xmax=LGT(ABS(Istop))                ! Find LOG of max X axis value
630   PRINT "Press CONT to display graph"
640   PRINT "Press CONT while in graph to return to BASIC"
650   PAUSE
660   OUTPUT KBD;CHR$(255);CHR$(75); ! Clear CRT
670   GINIT                               ! Initialize graphics
680   PLOTTER IS CRT,"INTERNAL"           ! Define plot to CRT
690   GRAPHICS ON                         ! Turn on graphics
700   MOVE 55,95                          ! Title graph
710   LABEL "Vt VS. Id"
720   MOVE 70,10                          ! Label X axis
730   LABEL "Id"
740   MOVE 0,53                           ! Label Y axis
750   LABEL "Vt"
760   VIEWPORT 30,120,20,85               ! Define soft clip limits
770   WINDOW Xmin,Xmax,Ymin,Ymax          ! Scale graph
780   X1=(Xmax-Xmin)/10                   ! Compute X axis increment
790   Y1=(Ymax-Ymin)/10                   ! Compute Y axis increment
800   GRID X1*2,Y1*2,Xmin,Ymin            ! Draw grid
810   PLOT Reading(*)                     ! Plot data
820   LORG 6                              ! Center characters
830   CLIP OFF                            ! Turn off soft clipping
840   FOR I=Xmin TO Xmax+.01*(X1) STEP 2*X1  ! Number X axis
850   CSIZE 4.5
860   MOVE I,Ymin-(Y1/3)
870   LABEL "10"
880   CSIZE 3
890   MOVE I+.5*X1,Ymin-(Y1/8)
900   LABEL USING "#,K";I
910   NEXT I
920   CSIZE 4
930   FOR I=Ymin TO Ymax+.01*Y1 STEP 2*Y1 ! number Y axis
940   MOVE Xmin-(1.3*X1),I+(.3*Y1)
950   LABEL USING "#,MDD.DDD";I
960   NEXT I
970   PAUSE
980   OUTPUT KBD;CHR$(255);CHR$(75); ! Turn off alpha display
990   GRAPHICS OFF                        ! Turn off graphics display
1000  END
```

APPENDIX A
Converting Applications Programs to QuickBASIC for IBM-PC Computers

INTRODUCTION

This appendix contains information on converting the applications programs in this manual to Microsoft QuickBASIC for use with IBM-PC AT and compatible computers.. Example programs are also included to demonstrate the process.

Computer Hardware Requirements

The following computer hardware is recommended:

- IBM-PC AT or compatible computer.
- EGA graphics adapter and monitor.
- IOtech Personal488, CEC PC-488, or National Instruments PC-II or PC-IIA IEEE-488 interface for the computer.

Computer Software Requirements

The following software is necessary:

- MS-DOS or PC-DOS version 3.30 or later.
- Microsoft QuickBASIC BASIC compiler, version 4.0 or later.
- Capital Equipment Corp. CEC-GRAPH graphics software, version 1.7 or later.
- IOtech Driver488 IEEE-488 bus driver, Rev. 2.3 or later.

Hardware/Software Installation

Make sure the IEEE-488 interface and Driver488 software driver are installed per manufacturer's recommendations. The board base I/O address, DMA and interrupt status, and board clock frequency must agree with the corresponding driver software settings.

Compiling and Linking Procedure

Follow the general procedure below to make an executable program from a program source listing.

1. Copy the CEC-GRAPH GRAPHQB.OBJ and GRPKG.OBJ files to your QuickBASIC working diskette or subdirectory.
2. Enter the QuickBASIC editor, and type in the desired program.
3. After checking for errors, save the source listing under a convenient filename, then exit the editor.
4. Compile the program by typing in the following:

   BC Filename <Enter>

Here, Filename is the name of the file assigned in step 3. Fix any errors that occur, and recompile if necessary.

5. Link the files to make an executable by typing in the following:

   LINK Filename GRAPHQB GRPKG <Enter>

Be sure to specify the BCOM library at the .LIB prompt if you wish to make a stand-alone executable. Note that you should not include GRAPHQB and GRPKG in the name list for programs that do not include plotting routines.

6. After linking, the program is ready to run. From the DOS prompt, simply type in the name of the program.

Running in the QuickBASIC Environment

Instead of separately compiling and linking, you can also run a program while in the QuickBASIC environment. To do so, you must add a DECLARE SUB statement for each CEC-GRAPH CALL used in the program, for example:

```
DECLARE SUB GRAPHXY
DECLARE SUB SCREENMODE
```

Declarations should be added at the front of each program as appropriate.

In addition, you must also load the GRAPHQB.LIB module when entering the editor as follows:

```
QB /L GRAPHQB <Enter>
```

You can then type in or load your program as usual.

Press shift F5 while in the editor to run a program.

Example Programs

The sample listings on the following pages are the translated versions of six example programs throughout this manual. The programs and reference areas of the manual are:

Program A-1, Diode Characterization: paragraph 2.6.
Program A-2, I_{CEO} Measurement: paragraph 3.7.
Program A-3, Common-emitter Test: paragraph 3.4.
Program A-4, Common-source Test: paragraph 4.4.
Program A-5, Self-bias Threshold Test: paragraph 8.5.
Program A-6, Gummel Plot: paragraph 3.5.

Example Plots

Figure A-1 through Figure A-6 show the example plots from the QuickBASIC example programs in this appendix. Figure A-1 was generated using an HPGL plotter, while Figure A-2 through Figure A-6 are printer graphics dumps generated with the aid of the DOS GRAPHICS command. In order to use GRAPHICS.COM, you should modify the corresponding program for SCREENMODE 6 and SCREEN 2 in order to support CGA graphics.

```
' DIODE CHARACTERIZATION PROGRAM, QUICKBASIC VERSION REV. 1.3 (Program A-1)
OPEN "\DEV\IEEEOUT" FOR OUTPUT AS #1     ' Open IEEE-488 output path.
OPEN "\DEV\IEEEIN" FOR INPUT AS #2       ' Open IEEE-488 input path.
IOCTL #1, "BREAK"                        ' Reset interface.
PRINT #1, "RESET"                        ' Warm start interface
PRINT #1, "CLEAR"                        ' Send device clear.
PRINT #1, "REMOTE 16"                    ' Put 236 in remote.
CLS                                      ' Clear CRT.
OPTION BASE 1
DIM RX(101), RY(101)                     ' Dimension reading arrays.
PRINT #1, "OUTPUT 16;F1,1X"              ' Source I, sweep mode.
PRINT #1, "OUTPUT 16;OOT1,0,0,OX"        ' Local sense, trigger on GET.
PRINT #1, "OUTPUT 16;L1,1X"              ' 1V compliance, 1.1V range.
PRINT #1, "OUTPUT 16;G5,2,1X"            ' Source,measure,no prefix,sweep data.
PRINT #1, "OUTPUT 16;M2,X"               ' SRQ on sweep done.
PRINT #1, "OUTPUT 16;BO,0,OX"            ' Program 0 bias value.
PRINT #1, "OUTPUT 16;Z1X"                ' Enable suppress
Istart = 0: Istop = .0001: Istep = .000001 ' Define current parameters.
Delay = 10                               ' Define 10msec delay.
PRINT #1, "OUTPUT 16;Q1,"; Istart; ","; Istop; ","; Istep; ",0,"; Delay; "X"
PRINT "Close lid, press any key to begin."
DO WHILE INKEY$ = "": LOOP               ' Wait for keypress.
PRINT #1, "OUTPUT 16;R1N1X"              ' Arm sweep, turn on 236 output.
PRINT #1, "TRIGGER 16"                   ' Trigger sweep.
WaitForSRQ: PRINT #1, "STATUS"           ' Get bus status.
INPUT #2, ST$                            ' Input status string.
IF MID$(ST$, 11, 2) = "SO" THEN GOTO WaitForSRQ ' Wait for SRQ.
PRINT #1, "SPOLL 16"                     ' Serial poll 236 to clear SRQ.
INPUT #2, SB
PRINT #1, "OUTPUT 16;NOX"                ' Turn off 236 output.
FOR I = 1 TO 101                         ' Loop for all 101 readings.
PRINT #1, "ENTER 16"                     ' Address 236 to talk.
INPUT #2, RX(I), RY(I)                   ' Input current and voltage readings.
NEXT I                                   ' Loop back for next reading.
CLOSE 1: CLOSE 2                         ' Close I/O files.
PRINT "Press key to display graph."
PRINT "Press key while in graph to end program."
DO WHILE INKEY$ = "": LOOP               ' Wait for keypress.
title$ = "DIODE TEST PROGRAM PLOT"       ' Plot data
CALL SCREENMODE(16)
SCREEN 9
CALL GRAPHXY(SEG RX(1), SEG RY(1), 101, 1, "If", 1, "Vf", title$, 1, 0, 2)
DO WHILE INKEY$ = "": LOOP
END
```

```
'BIPOLAR TRANSISTOR LEAKAGE TEST, QUICKBASIC VERSION. REV. 1.3 (Program A-2)
OPEN "\DEV\IEEEOUT" FOR OUTPUT AS #1     ' Open IEEE-488 output path.
OPEN "\DEV\IEEEIN" FOR INPUT AS #2       ' Open IEEE-488 input path.
IOCTL #1, "BREAK"                        ' Reset interface.
PRINT #1, "RESET"                        ' Warm start interface
PRINT #1, "CLEAR"                        ' Send device clear.
PRINT #1, "REMOTE 16"                    ' Put unit in remote.
CLS                                      ' Clear CRT.
OPTION BASE 1
DIM RX(101), RY(101)                     ' Dimension reading arrays.
PRINT #1, "OUTPUT 16;F0,1X"              ' Source V, sweep mode.
PRINT #1, "OUTPUT 16;O0T1,0,0,0X"        ' Local sense, trigger on GET.
PRINT #1, "OUTPUT 16;L1E-3,0X"           ' 1mA compliance,autorange measure.
PRINT #1, "OUTPUT 16;G5,2,1X"            ' Source, measure, no prefix, sweep.
PRINT #1, "OUTPUT 16;M2,X"               ' SRQ on sweep done.
PRINT #1, "OUTPUT 16;S2X"                ' Line cycle integration.
PRINT #1, "OUTPUT 16;B0,0,0X"            ' Program 0 bias value.
PRINT #1, "OUTPUT 16;Z1X"                ' Enable suppress.
Vstart = 0: Vstop = 10: Vstep = .1       ' Define voltage sweep parameters.
Delay = 100                              ' Define 100msec delay.
PRINT #1, "OUTPUT 16;Q1,"; Vstart; ","; Vstop; ","; Vstep; ",0,"; Delay; "X"
PRINT "Close lid, press any key to begin."
DO WHILE INKEY$ = "": LOOP               ' Wait for keypress.
PRINT #1, "OUTPUT 16;R1N1X"              ' Arm sweep, turn on 236 output.
PRINT #1, "TRIGGER 16"                   ' Trigger sweep.
WaitForSRQ: PRINT #1, "STATUS"           ' Get bus status.
INPUT #2, ST$                            ' Input status string.
IF MID$(ST$, 11, 2) = "S0" THEN GOTO WaitForSRQ ' Wait for SRQ.
PRINT #1, "SPOLL 16"                     ' Serial poll 236 to clear SRQ.
INPUT #2, SB
PRINT #1, "OUTPUT 16;N0X"                ' Turn off 236 output.
FOR I = 1 TO 101                         ' Loop for all 101 readings.
PRINT #1, "ENTER 16"                     ' Address 236 to talk.
INPUT #2, RX(I), RY(I)                   ' Input voltage and current readings.
NEXT I                                   ' Loop back for next reading.
CLOSE 1: CLOSE 2                         ' Close I/O files.
PRINT "Press key to display graph."
PRINT "Press key while in graph to end program."
DO WHILE INKEY$ = "": LOOP               ' Wait for keypress.
title$ = "Iceo vs. Vceo": xaxis$ = "Vceo": yaxis$ = "Iceo"' Plot data
X% = 1: Y% = 1: SYMBOL% = 0: NUM% = 101: PEN.NUM% = 2: LIN% = 1: MODE% = 16
CALL GRID(1)
CALL SCREENMODE(MODE%)
SCREEN 9
CALL GRAPHXY(SEG RX(1), SEG RY(1), NUM%, X%, xaxis$, Y%, yaxis$, title$, LIN%, SYMBOL
%, PEN.NUM%)
DO WHILE INKEY$ = "": LOOP
 END
```

```
'COMMON-EMITTER TEST PROGRAM, QUICKBASIC VERSION. REV. 1.3 (Program A-3)
OPEN "\DEV\IEEEOUT" FOR OUTPUT AS #1     ' Open IEEE-488 output path.
OPEN "\DEV\IEEEIN" FOR INPUT AS #2       ' Open IEEE-488 input path.
IOCTL #1, "BREAK"                        ' Reset interface.
PRINT #1, "RESET"                        ' Warm start interface
PRINT #1, "CLEAR"                        ' Send device clear.
PRINT #1, "REMOTE 16,17"                 ' Put units in remote.
CLS                                      ' Clear CRT.
OPTION BASE 1
DIM R(5, 101, 2), RX(101), RY(101)       ' Dimension reading arrays.
REM ******* Unit 1 SETUP (Sweeps Ib) *********************************
PRINT #1, "OUTPUT 16;F1,1X"              ' Source I, sweep mode.
PRINT #1, "OUTPUT 16;L1,1X"              ' 1V compliance,1.1V range.
PRINT #1, "OUTPUT 16;O0X"                ' Local sense
PRINT #1, "OUTPUT 16;T1,1,2,0X"          ' Output trigger on end of delay.
PRINT #1, "OUTPUT 16;B0,0,0X"            ' Program 0 bias value
Istart = .00001: Istop = .00005: Istep = .00001 ' Define sweep parameters.
Delay = 100                              ' 100msec delay.
PRINT #1, "OUTPUT 16;Q1,"; Istart; ","; Istop; ","; Istep; ",0,"; Delay; "X"
REM **********Unit 2 SETUP (Sweeps Vce, measures Ic) ******************
PRINT #1, "OUTPUT 17;F0,1X"              ' Source V, sweep mode.
PRINT #1, "OUTPUT 17;O0X"                ' Local sensing.
PRINT #1, "OUTPUT 17;L100E-3,0X"         ' 100mA compliance, autorange measure.
PRINT #1, "OUTPUT 17;G5,2,1X"            ' Source,measure,no prefix.
PRINT #1, "OUTPUT 17;T3,0,0,0X"          ' Trigger on external.
PRINT #1, "OUTPUT 17;M2,X"               ' SRQ on sweep done.
PRINT #1, "OUTPUT 17;B0,0,0X"            ' Program 0 bias value
PRINT #1, "OUTPUT 17;Z1X"                ' Enable suppress
Vstart = 0: Vstop = 10: Vstep = .1       ' Define sweep parameters.
PRINT #1, "OUTPUT 17;Q1,"; Vstart; ","; Vstop; ","; Vstep; ",0,"; Delay; "X"
PRINT "Close lid, press any key to begin"
DO WHILE INKEY$ = "": LOOP
PRINT #1, "OUTPUT 16;R1N1X"              ' Arm Unit 1, turn on output.
PRINT #1, "OUTPUT 17;R1N1X"              ' Arm Unit 2, turn on output.
FOR I = 1 TO 5                           ' Loop for all 5 sweeps.
PRINT "Generating sweep"; I
PRINT #1, "TRIGGER 16"                   ' Trigger Unit 1.
WaitForSRQ: PRINT #1, "STATUS"           ' Get bus status.
INPUT #2, ST$
IF MID$(ST$, 11, 2) = "S0" THEN GOTO WaitForSRQ ' Wait for SRQ.
PRINT #1, "SPOLL 17"                     ' Serial poll Unit 2 to clear SRQ.
INPUT #2, SB
FOR J = 1 TO 101                         ' Loop for all 101 readings.
PRINT #1, "ENTER 17"                     ' Address Unit 2 to talk.
INPUT #2, R(I, J, 1), R(I, J, 2)         ' Get Vce and Ic data from Unit 2.
NEXT J                                   ' Loop back for next reading.
NEXT I                                   ' Loop back for next sweep.
PRINT #1, "OUTPUT 16;N0X"                ' Turn off Unit 1 output.
PRINT #1, "OUTPUT 17;N0X"                ' Turn off Unit 2 output.
CLOSE 1: CLOSE 2                         ' Close I/O files.
PRINT "Press any key to display graph."
PRINT "Press any key while in graph to end program."
DO WHILE INKEY$ = "": LOOP
```

```
Ymin = 1E+32: Ymax = -1E+32                ' Find maximum and minimum Ic.
FOR I = 1 TO 5
FOR J = 1 TO 101
IF R(I, J, 2) < Ymin THEN Ymin = R(I, J, 2)
IF R(I, J, 2) > Ymax THEN Ymax = R(I, J, 2)
NEXT J, I
title$ = "COMMON-EMITTER CHARACTERISTICS" ' Plot data.
xaxis$ = "Vce": yaxis$ = "Ic"
X% = 1: Y% = 1: SYMBOL% = 0: NUM% = 101: PEN.NUM% = 2: LIN% = 1: mode% = 16
CALL SCREENMODE(mode%)
SCREEN 9
Xmin = 0!: Xmax = 10!
CALL SCALE(Xmin, Ymin, Xmax, Ymax)
FOR I = 1 TO 5                             ' Loop for all five curves.
FOR J = 1 TO 101                           '
RX(J) = R(I, J, 1): RY(J) = R(I, J, 2)  ' Transfer readings to plot arrays.
NEXT J                                     ' Loop back for next data point.
IF I = 2 THEN X% = 0: Y% = 0               ' No axes after first curve.
CALL GRAPHXY(SEG RX(1), SEG RY(1), NUM%, X%, xaxis$, Y%, yaxis$, title$, LIN%, SYMBOL
%, PEN.NUM%)
NEXT I                                     ' Loop back for next curve.
DO WHILE INKEY$ = "": LOOP
END
```

```
'COMMON-SOURCE TEST PROGRAM, QUICKBASIC VERSION. REV. 1.3 (Program A-4)
OPEN "\DEV\IEEEOUT" FOR OUTPUT AS #1     ' Open IEEE-488 output path.
OPEN "\DEV\IEEEIN" FOR INPUT AS #2       ' Open IEEE-488 input path.
IOCTL #1, "BREAK"                        ' Reset interface.
PRINT #1, "RESET"                        ' Warm start interface
PRINT #1, "CLEAR"                        ' Send device clear.
PRINT #1, "REMOTE 16,17"                 ' Put units in remote.
CLS                                      ' Clear CRT.
OPTION BASE 1
DIM R(5, 101, 2), RX(101), RY(101)       ' Dimension reading arrays.
REM ******* UNIT 1 SETUP (Sweeps Vgs) *********************************
PRINT #1, "OUTPUT 16;F0,1X"              ' Source V, sweep mode.
PRINT #1, "OUTPUT 16;L1E-3,7X"           ' 1mA compliance,1mA range.
PRINT #1, "OUTPUT 16;O0T1,1,2,0X"        ' Local sense, out trig end of delay.
PRINT #1, "OUTPUT 16;B0,0,0X"            ' Program 0 bias.
Vgstart = -2: Vgstop = 0: Vgstep = .5    ' Define sweep parameters.
Delay = 10                               ' 10msec delay.
PRINT #1, "OUTPUT 16;Q1,"; Vgstart; ","; Vgstop; ","; Vgstep; ",0,"; Delay; "X"
REM **********UNIT 2 SETUP (Sweeps Vds, measures Id) ********************
PRINT #1, "OUTPUT 17;F0,1X"              ' Source V, sweep mode.
PRINT #1, "OUTPUT 17;O0X"                ' Local sensing.
PRINT #1, "OUTPUT 17;L100E-3,0X"         ' 100mA compliance, autorange measure.
PRINT #1, "OUTPUT 17;G5,2,1X"            ' Source,measure,no prefix.
PRINT #1, "OUTPUT 17;M2,T3,0,0,0X"       ' SRQ, trigger on external.
PRINT #1, "OUTPUT 17;B0,0,0X"            ' Program 0 bias.
PRINT #1, "OUTPUT 17;Z1X"                ' Enable suppress
Vdstart = 0: Vdstop = 10: Vdstep = .1    ' Define sweep parameters.
PRINT #1, "OUTPUT 17;Q1,"; Vdstart; ","; Vdstop; ","; Vdstep; ",0,"; Delay; "X"
PRINT "Close lid, press any key to begin"
DO WHILE INKEY$ = "": LOOP
PRINT #1, "OUTPUT 16;R1N1X"              ' Arm Unit 1, turn on output.
PRINT #1, "OUTPUT 17;R1N1X"              ' Arm Unit 2, turn on output.
FOR I = 1 TO 5                           ' Loop for all 5 sweeps.
PRINT "Generating sweep"; I
PRINT #1, "TRIGGER 16"                   ' Trigger Unit 1.
WaitForSRQ: PRINT #1, "STATUS"           ' Get bus status.
INPUT #2, ST$
IF MID$(ST$, 11, 2) = "S0" THEN GOTO WaitForSRQ ' Wait for SRQ.
PRINT #1, "SPOLL 17"                     ' Serial poll Unit 2 to clear SRQ.
INPUT #2, SB
FOR J = 1 TO 101                         ' Loop for all 101 readings.
PRINT #1, "ENTER 17"                     ' Address Unit 2 to talk.
INPUT #2, R(I, J, 1), R(I, J, 2)         ' Get Vce and Ic data from Unit 2.
NEXT J                                   ' Loop back for next reading.
NEXT I                                   ' Loop back for next sweep.
PRINT #1, "OUTPUT 16;N0X"                ' Turn off Unit 1 output.
PRINT #1, "OUTPUT 17;N0X"                ' Turn off Unit 2 output.
CLOSE 1: CLOSE 2                         ' Close I/O files.
PRINT "Press any key to display graph."
PRINT "Press any key while in graph to end program."
DO WHILE INKEY$ = "": LOOP
Ymin = 1E+32: Ymax = -1E+32              ' Find maximum and minimum Id.
FOR I = 1 TO 5
```

```
FOR J = 1 TO 101
IF R(I, J, 2) < Ymin THEN Ymin = R(I, J, 2)
IF R(I, J, 2) > Ymax THEN Ymax = R(I, J, 2)
NEXT J, I
Xmin = 0!: Xmax = 10!
CALL SCALE(Xmin, Ymin, Xmax, Ymax)
title$ = "COMMON-SOURCE CHARACTERISTICS" ' Plot data.
xaxis$ = "Vds": yaxis$ = "Id"
X% = 1: Y% = 1: SYMBOL% = 0: NUM% = 101: PEN.NUM% = 2: LIN% = 1: MODE% = 16
CALL SCREENMODE(MODE%)
SCREEN 9
FOR I = 1 TO 5                          ' Loop for all five curves.
FOR J = 1 TO 101
RX(J) = R(I, J, 1): RY(J) = R(I, J, 2)  ' Transfer readings to plot arrays.
NEXT J                                  ' Loop back for next data point.
IF I = 2 THEN X% = 0: Y% = 0            ' Axes on first curve only.
CALL GRAPHXY(SEG RX(1), SEG RY(1), NUM%, X%, xaxis$, Y%, yaxis$, title$, LIN%, SYMBOL
%, PEN.NUM%)
NEXT I                                  ' Loop back for next curve.
DO WHILE INKEY$ = "": LOOP
END
```

```
'LOG SWEEP SELF BIAS THRESHOLD VOLTAGE, QUICKBASIC VER. REV. 1.3 (Pgm. A-5)
OPEN "\DEV\IEEEOUT" FOR OUTPUT AS #1     ' Open IEEE-488 output path.
OPEN "\DEV\IEEEIN" FOR INPUT AS #2       ' Open IEEE-488 input path.
IOCTL #1, "BREAK"                        ' Reset interface.
PRINT #1, "RESET"                        ' Warm start interface
PRINT #1, "CLEAR"                        ' Send device clear.
PRINT #1, "REMOTE 16,17"                 ' Put units in remote.
CLS                                      ' Clear CRT.
OPTION BASE 1
DIM RX(51), RY(51)                       ' Dimension reading arrays.
REM ******* Unit 1 SETUP (Sources -Id, measures -Vt) **********************
PRINT #1, "OUTPUT 16;F1,1X"              ' Source I, sweep mode.
PRINT #1, "OUTPUT 16;L10,2X"             ' 10V compliance,11V range.
PRINT #1, "OUTPUT 16;O0T1,0,0,0X"        ' Local sense, out trig end of delay.
PRINT #1, "OUTPUT 16;B0,0,0X"            ' Program 0 bias value.
PRINT #1, "OUTPUT 16;G5,2,1X"            ' Source,measure,no prefix,sweep data.
PRINT #1, "OUTPUT 16;S2P0X"              ' Line cycle integration,filter off.
PRINT #1, "OUTPUT 16;B0,0,0X"            ' Program 0 bias value.
PRINT #1, "OUTPUT 16;M2,0Z0X"            ' SRQ on sweep done,suppress off.
Istart = -1E-09: Istop = -.0001: Points = 1' Define sweep parameters.
Delay = 200                              ' Define 200msec delay.
PRINT #1, "OUTPUT 16;Q2,"; Istart; ","; Istop; ","; Points; ",0,"; Delay; "X"
REM **********Unit 2 SETUP (Sources -Vds) ********************************
PRINT #1, "OUTPUT 17;F0,0X"              ' Source V, DC mode.
PRINT #1, "OUTPUT 17;O1X"                ' Remote sensing.
PRINT #1, "OUTPUT 17;L100E-3,9X"         ' 100mA compliance, 100mA range.
PRINT #1, "OUTPUT 17;T1,0,0,0X"          ' Trigger on GET.
Vds = -10                                ' Define -10V Vds value.
PRINT #1,"OUTPUT 17;B"; Vds; ",3,"; Delay; "X" ' Program DC, 11OV range,delay
PRINT "Close lid, press any key to begin"
DO WHILE INKEY$ = "": LOOP
PRINT #1, "OUTPUT 16;R1N1X"              ' Arm Unit 1, turn on output.
PRINT #1, "OUTPUT 17;R1N1X"              ' Arm Unit 2, turn on output.
PRINT #1, "TRIGGER 17"                   ' Trigger Unit 2.
PRINT #1, "TRIGGER 16"                   ' Trigger Unit 1.
WaitForSRQ: PRINT #1, "STATUS"           ' Get bus status.
INPUT #2, ST$
IF MID$(ST$, 11, 2) = "S0" THEN GOTO WaitForSRQ ' Wait for SRQ.
PRINT #1, "SPOLL 16"                     ' Serial poll Unit 1 to clear SRQ.
INPUT #2, SB
FOR I = 1 TO 51                          ' Loop for all 51 readings.
PRINT #1, "ENTER 16"                     ' Address Unit 1 to talk.
INPUT #2, RX(I), RY(I)                   ' Get -Id and -Vt data from Unit 1.
RX(I) = ABS(RX(I)): RY(I) = -RY(I)       ' Sign adjust Id and Vt.
NEXT I                                   ' Loop back for next reading.
PRINT #1, "OUTPUT 16;N0X"                ' Turn off Unit 1 output.
PRINT #1, "OUTPUT 17;N000X"              ' Turn off Unit 2 output,local sense.
CLOSE 1: CLOSE 2                         ' Close I/O files.
PRINT "Press any key to display graph."
PRINT "Press any key while in graph to end program."
DO WHILE INKEY$ = "": LOOP
title$ = "Vt vs. Id"                     ' Plot data.
xaxis$ = "Id": yaxis$ = "Vt"
```

```
X% = 1: Y% = 1: SYMBOL% = 0: NUM% = 51: PEN.NUM% = 2: LIN% = 1: mode% = 16
CALL GRID(1)                                ' Enable grid.
CALL LOGAXIS(1, 0)                          ' Log axis on X axis only.
CALL SCREENMODE(mode%)
SCREEN 9
CALL GRAPHXY(SEG RX(1), SEG RY(1), NUM%, X%, xaxis$, Y%, yaxis$, title$, LIN%, SYMBOL
%, PEN.NUM%)
DO WHILE INKEY$ = "": LOOP
END
```

```
'GUMMEL PLOT TEST PROGRAM, QUICKBASIC VERSION REV. 1.3 (Program A-6)
OPEN "\DEV\IEEEOUT" FOR OUTPUT AS #1     ' Open IEEE-488 output path.
OPEN "\DEV\IEEEIN" FOR INPUT AS #2       ' Open IEEE-488 input path.
IOCTL #1, "BREAK"                        ' Reset interface.
PRINT #1, "RESET"                        ' Warm start interface
PRINT #1, "CLEAR"                        ' Send device clear.
PRINT #1, "REMOTE 16,17"                 ' Put units in remote.
CLS                                      ' Clear CRT.
OPTION BASE 1
DIM R(71, 3), RX(71), RY(71)             ' Dimension reading arrays.
REM ******* UNIT 1 SETUP (Sweeps Vbe, measures Ib) ***************************
PRINT #1, "OUTPUT 16;F0,1X"              ' Source V, sweep mode.
PRINT #1, "OUTPUT 16;L1E-3,0X"           ' 1mA compliance,autorange measure.
PRINT #1, "OUTPUT 16;O0T3,4,2,0X"        ' Local sense, ext trig end of delay.
PRINT #1, "OUTPUT 16;G5,2,1X"            ' Source,measure,no prefix,sweep data.
PRINT #1, "OUTPUT 16;S2Z0X"              ' Line cycle integration,suppress off.
PRINT #1, "OUTPUT 16;B0,0,0X"            ' Program 0 bias value.
Vstart = .7: Vstop = 0!: Vstep = -.01    ' Define sweep parameters.
Delay = 10                               ' 10msec delay.
PRINT #1, "OUTPUT 16;Q1,"; Vstart; ","; Vstop; ","; Vstep; ",0,"; Delay; "X"
REM **********UNIT 2 SETUP (Sources Vce, measures Ic) ********************
PRINT #1, "OUTPUT 17;F0,1X"              ' Source V, sweep mode.
PRINT #1, "OUTPUT 17;O0X"                ' Local sensing.
PRINT #1, "OUTPUT 17;L100E-3,0X"         ' 100mA compliance, autorange measure.
PRINT #1, "OUTPUT 17;G4,2,1X"            ' Measure,no prefix.
PRINT #1, "OUTPUT 17;T3,1,4,0X"          ' Trigger on external.
PRINT #1, "OUTPUT 17;B0,0,0X"            ' Program 0 bias value.
PRINT #1, "OUTPUT 17;S2Z0X"              ' Line cycle integration,suppress off.
Vce = 10                                 ' Define 10V constant Vce.
PRINT #1, "OUTPUT 17;Q0,"; Vce; ",0,"; Delay; ",71X" ' Program sweep.
PRINT "Close lid, press any key to begin"
DO WHILE INKEY$ = "": LOOP
PRINT #1, "OUTPUT 16;R1N1X"              ' Arm Unit 1, turn on output.
PRINT #1, "OUTPUT 17;R1N1X"              ' Arm Unit 2, turn on output.
PRINT #1, "OUTPUT 16;H0X"                ' Trigger Unit 1.
FOR I = 71 TO 1 STEP -1                  ' Loop for all 71 readings.
PRINT #1, "ENTER 16"                     ' Address Unit 1 to talk.
INPUT #2, R(I, 1), R(I, 2)               ' Input Vbe and Ib from Unit 1.
PRINT #1, "ENTER 17"                     ' Address Unit 2 to talk.
INPUT #2, R(I, 3)                        ' Input Ic from Unit 2.
IF R(I, 2) < 1E-14 THEN R(I, 2) = 1E-14  ' Set Ib noise floor.
IF R(I, 3) < 1E-14 THEN R(I, 3) = 1E-14  ' Set Ic noise floor.
NEXT I                                   ' Loop for next readings.
PRINT #1, "OUTPUT 16;N0X"                ' Put Unit 1 in standby.
PRINT #1, "OUTPUT 17;N0X"                ' Put Unit 2 in standby.
CLOSE 1: CLOSE 2                         ' Close I/O files.
PRINT "Press any key to display graph."
PRINT "Press any key while in graph to end program."
DO WHILE INKEY$ = "": LOOP
Ymin = 1E+32: Ymax = -1E+32              ' Find maximum Ic and minimum Ib.
FOR I = 1 TO 71
IF R(I, 2) < Ymin THEN Ymin = R(I, 2)
IF R(I, 3) > Ymax THEN Ymax = R(I, 3)
```

```
NEXT I
Xmin = Vstop: Xmax = Vstart
CALL LOGAXIS(0, 1)                          ' Log on Y axis only.
CALL SCALE(Xmin, Ymin, Xmax, Ymax)          ' Scale graph.
title$ = "Ib, Ic vs. Vbe"                   ' Plot data.
xaxis$ = "Vbe": yaxis$ = "Ib & Ic"
X% = 1: Y% = 1: SYMBOL% = 0: NUM% = 71: PEN.NUM% = 2: LIN% = 1: MODE% = 16
CALL SCREENMODE(MODE%)
SCREEN 9
FOR I = 2 TO 3                              ' Loop for Ib and Ic curves.
FOR J = 1 TO 71                             '
RX(J) = R(J, 1): RY(J) = R(J, I)            ' Transfer readings to plot arrays.
NEXT J                                      ' Loop back for next data point.
IF I = 3 THEN X% = 0: Y% = 0                ' Axes on first curve only.
CALL GRAPHXY(SEG RX(1), SEG RY(1), NUM%, X%, xaxis$, Y%, yaxis$, title$, LIN%, SYMBOL
%, PEN.NUM%)
NEXT I                                      ' Loop back for next curve.
DO WHILE INKEY$ = "": LOOP
END
```

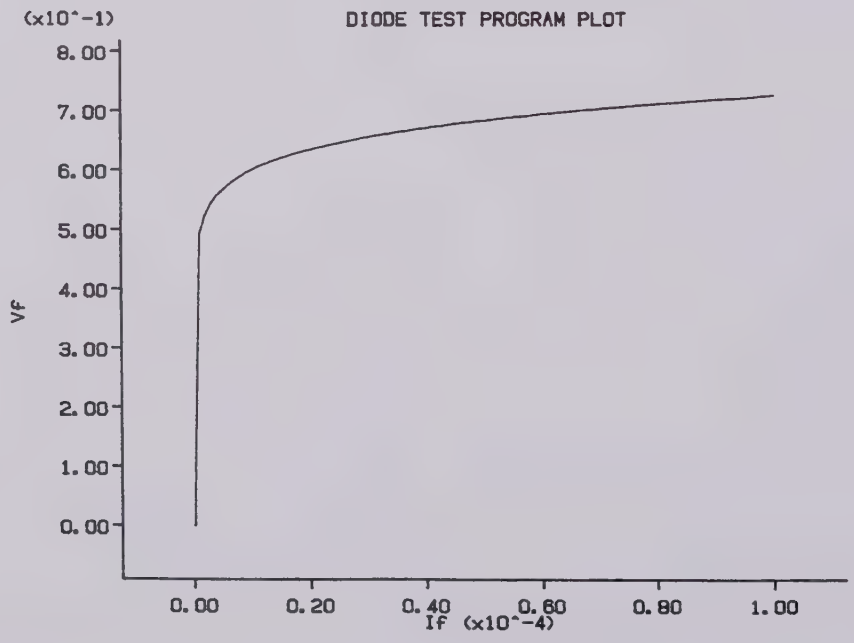


Figure A-1. Example Test Plot Using HPGL Plotter (from Program A-1)

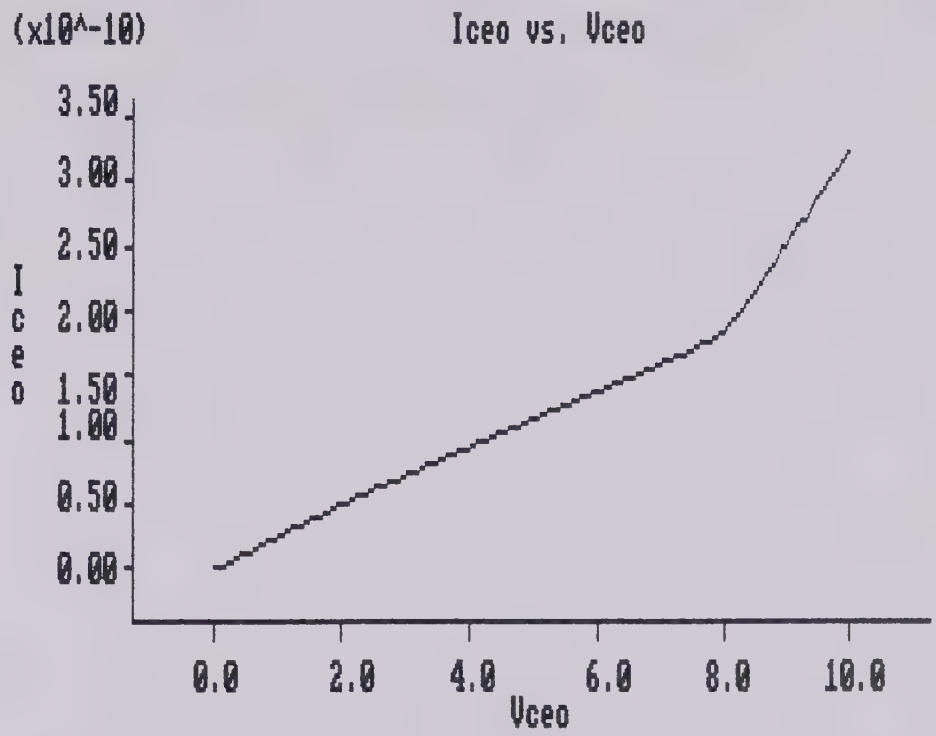


Figure A-2. I_{CEO} Test Plot Using Graphics Dump to Printer (from Program A-2)

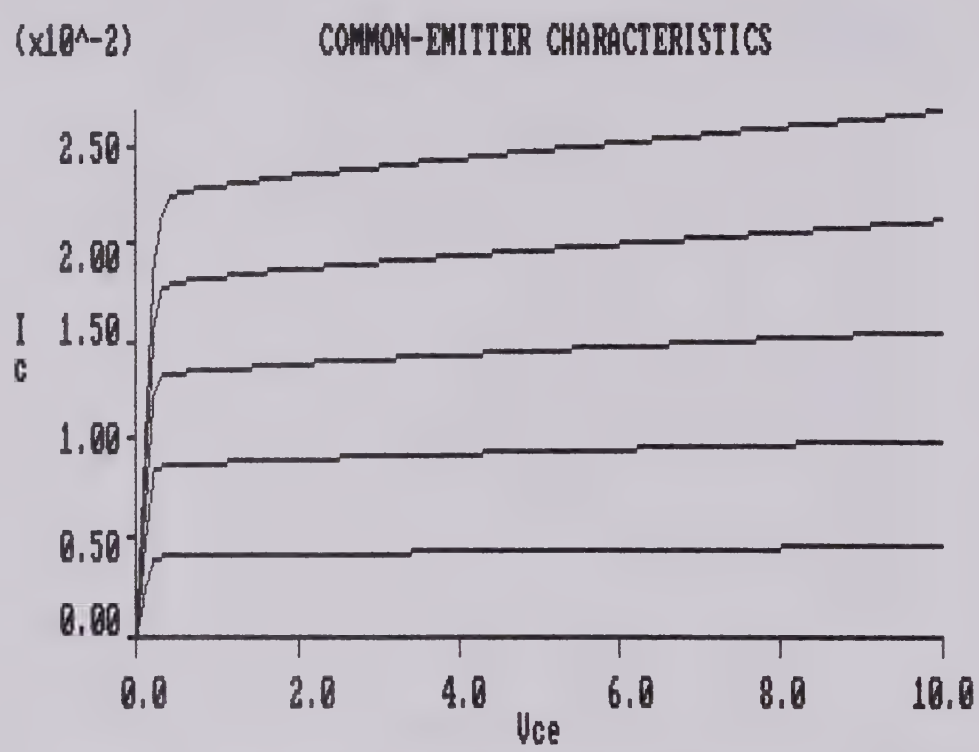


Figure A-3. Common-emitter Characteristic Plot Using Graphics Dump to Printer (from Program A-3)

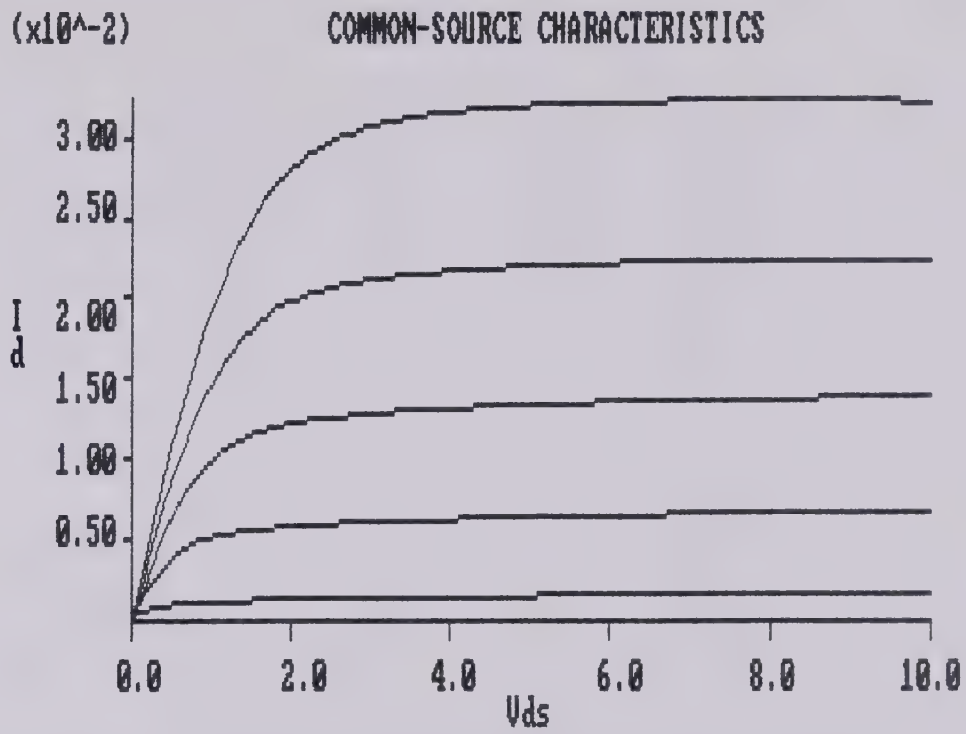


Figure A-4. Common -source Characteristic Plot Using Graphics Dump to Printer (from Program A-4)

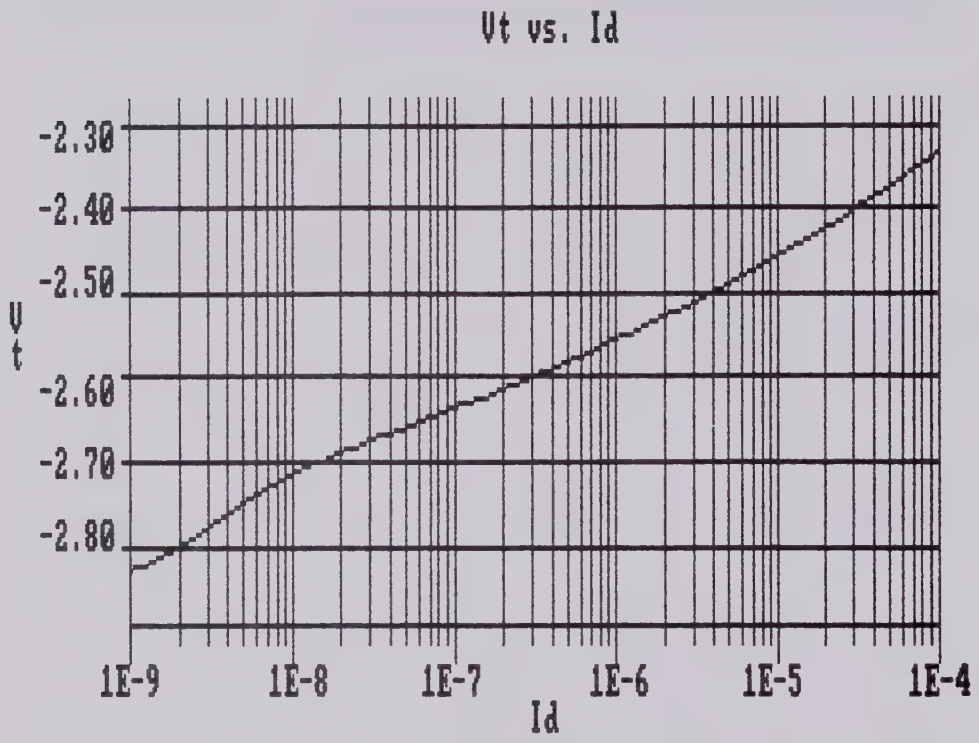


Figure A-5. Threshold Test Plot Using Graphics Dump to Printer (from Program A-5)

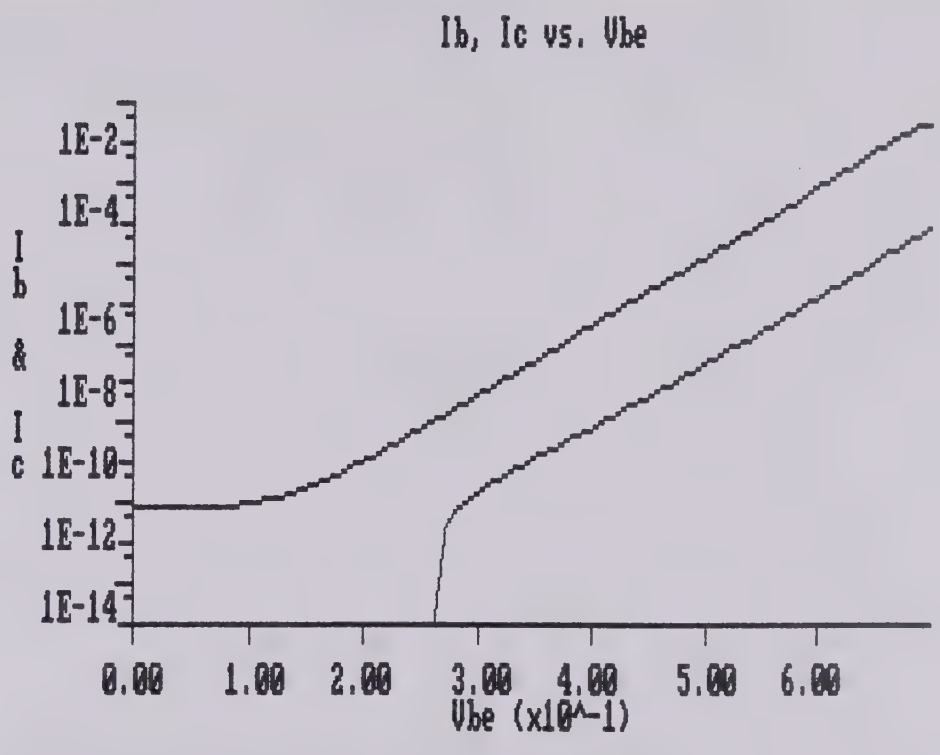


Figure A-6. Gummel Plot Using Graphics Dump to Printer (from Program A-6)

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... ve Gate Voltage

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